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[625 .251]

Some considerations on the cause of wheel sliding,

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The wheel sliding as caused by locking the wheels due to excessive brake block pressure is known only too well both in its cause and effect. Apart from this, this type of wheel locking is usually encountered shortly before stopping and provided, as is mostly the case, that the resultant slide flat spots are not more than about 0.5 mm. (0.0197 in.) deep will not lead to any detrimental effects since flat spots of this magnitude will be usually rolled out after a few hundred revolutions of the wheel.

Quite different in their effects are the results of continuous wheel sliding which having started unobserved at the beginning of a trip might often continue for an appreciable distance. The results of such continuous sliding have sometimes led to considerable damage of the wheels and bogies involved, to cracks and fractures of rails and even to derailments, particularly when the damaged wheels slide over switches.

The dangers resulting from extended wheel sliding are indicated by the fact that sometimes continuous sliding has been encountered for a length of 15 km. (9 miles) the depth of the resultant flat spot reaching a magnitude of up to 18 mm. ($^{45}/_{64}''$). Sliding of this type is often encountered in cold weather with goods trains equipped with continuous brakes, partly because of the lower values of the coefficient of friction μ between rail and wheel, partly because of air leakage from the main brake line preventing complete release, and partly because of incomplete release due to fault of personnel or equipment. The effectiveness of the latter in causing wheel sliding is accentuated in cold weather by the frost on the rails, which reduces the value of μ, whilst in contrast the brake blocks are in positive and dry contact with the wheels. On the other hand the viscosity of the journal grease might well be high, this again making the rotation of the wheels more difficult. Then again due to free coupling slack goods trains are started in a series of impacts from car to car, this resulting in instantaneous load transfer, whilst the forces involved will endeavour to accelerate the car from rest to a certain speed instantaneously, a process which will be opposed not only by the translatory inertia of the vehicle, but also by the rotative inertia of the wheels. Furthermore the hysterisis of the brake gear opposes the release of the brakes,

whilst the rolling resistance of the car is in obvious opposition to the normal functioning of the wheels.

We are thus faced with a number of factors all conspiring to oppose the rolling of the wheels, particularly when starting long goods trains, equipped with continuous brakes, in cold weather. Since large capacity waggons equipped with air brakes are being widely introduced in a number of countries the cause of wheel sliding at starts will be dealt with in the following in somewhat greater detail in an attempt to indicate the forces involved and thus also the remedies which might help in reducing incedence of an occurrence extremely undesirable in railway operation.

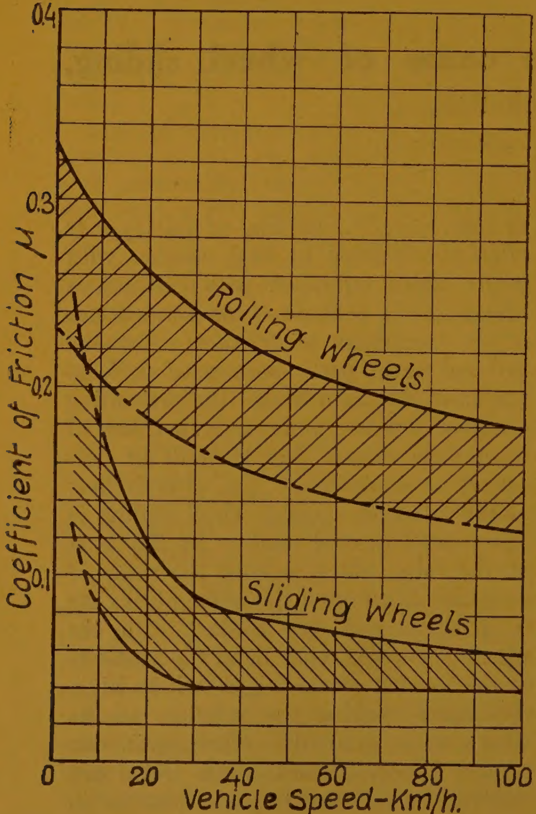

Fig. 1. — Coefficient of friction between rail and wheel.

The possibility of incurring wheel sliding is obviously to an over-riding extent influenced by the values of the coefficient of friction between rail and wheel and between brake block and wheel. This subject is dealt with exhaustively in the literature so that in the following it will suffice to indicate only its broad outlines.

The values of the coefficient of rolling friction between wheel and rail are shown in Fig. 1 for both dry and wet rails, the values being based on a synthesis due to KOTHER (1) (*) whilst the values of the coefficient of friction encountered with the sliding wheel, also shown in Fig. 1, are due to METZKOW (2). The significant point about these curves is that whilst in the case of the rolling wheel the value of μ is reduced gradually with increasing vehicle speeds, in the case of the sliding wheel μ drops very rapidly until a speed of about 30 km./h. (18.64 m.p.h.) is attained. Above this speed the value of μ is reduced further, but at a very much reduced rate.

The trend of values of the coefficient of friction between brake block and wheel are indicated in Fig. 2 showing the results obtained by EGORCHENKO (3) by tests with goods waggons having 1 m. (3′3 3/8″) diameter wheels and fitted with brake blocks having an effective area of 344 cm² (53.329 sq. in.). These are given here because in common to the classic tests due to GALTON (4) they were carried out on the road and not on test rigs as in the

(*) Numbers between parentheses refer to the Bibliography at the end of the article.

case of tests carried out at *Grunewald* (5) and at the *University of Illinois* (6). However it should be mentioned that because of a certain amount of distortion, encountered at higher pressure values with the brake gear cross-members connecting the brake blocks of the left and right wheel, the curves for pressure values in excess of 0.85 t. must be treated with reserve.

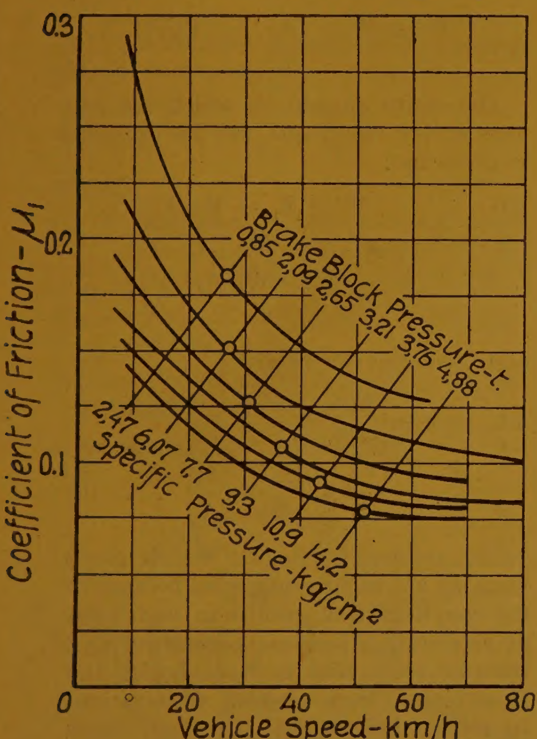

Fig. 2. — Coefficient of friction between brake block and wheel.

The load transfer due to tractive effort was dealt with by the Author (7) for the case of railcars. In the case of double bogie waggons provided with brake blocks on the inside of the wheels only (Fig. 3), the following will apply :

The rear bogie (in the direction of motion) will be unloaded by the amount Δ W. To determine the magnitude of this we must write the equation of all moments about the transverse axis 0 located at the height $(h_2 + h_3)$ of the centre line of the couplings, i.e. :

$$W c_b \mu_1 h_1 + R h_2 + \frac{L}{2}\left(\frac{W}{2} - \Delta W\right) - \frac{L}{2}\left(\frac{W}{2} + \Delta W\right) = 0 \quad . \; . \; . \; . \; . \; . \quad (1)$$

where

W = Weight of waggon body and load.

c_b = Brake ratio.

μ_1 = Coefficient of friction between brake block and wheel at the speed concerned.

R = Retarding force.

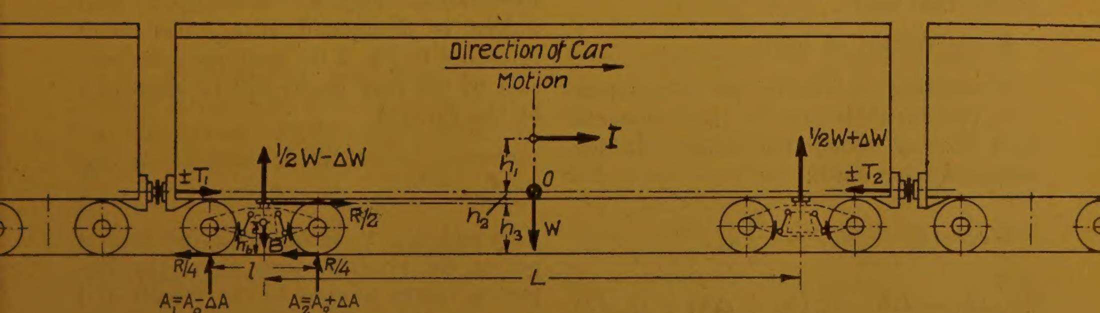

Fig. 3. — Forces in a braked waggon.

$I = Wc_b\mu_1$ = Inertia force applied at centre of gravity of waggon body.

Since the retarding force R is equal to the product of the brake block pressure P and the coefficient of friction μ_1 we can write :

$$Wc_b\mu_1 h_1 + c_b P h_2 - L\Delta W = 0 \quad . \quad (1a)$$

and consequently

$$\Delta W = \frac{Wc_b\mu_1 h_1 + c_b P h_2}{L}$$

$$= \frac{Ih_1 + c_b P h_2}{L} \quad . \; . \; . \quad (2)$$

As indicated in Fig. 3 the load upon the front bogie is increased by the amount ΔW, whilst that carried by the rear bogie is reduced by the equivalent amount.

So far as the bogies themselves are concerned they are subjected to the action of the following forces.

$Ac_b\mu_1$ = Inertia force applied to the centre of gravity of the bogie.

$\frac{R}{2}$ = Retarding force due to the two axles of the bogie.

This is applied at the point of contact between rail and wheels.

A_1 and A_2 = Vertical reaction forces of the axle loads.

B' = Weight of bogie.

Proceeding similarly as for equation (1) but this time for the transverse axis passing along the bolster at the height h_b, we have :

$$B'c_b\mu_1(h_3 - h_b) + \frac{R}{2}h_3$$

$$+ \frac{l}{2}(A_0 - \Delta A) - \frac{l}{2}(A_0 + \Delta A) = 0 \quad . \quad (3)$$

Substituting $P\mu_1$ for R and abreviating :

$$B'c_b\mu_1(h_3 - h_b) + P\mu_1 h_3 - l\Delta A = 0 \quad . \quad (3a)$$

and

$$\Delta A = \frac{B'c_b\mu_1(h_3 - h_b) + P\mu_1 h_3}{l} \quad . \quad (4)$$

The entire amount by which the rear axle of the rear bogie will be unloaded is given by :

$$\frac{\Delta W}{2} + \Delta A = \frac{Wc_b\mu_1 h_1 + P\mu_1 h_2}{2L}$$

$$+ \frac{B'c_b\mu_1(h_3 - h_b) + P\mu_1 h_3}{l} \quad . \; . \quad (5)$$

and from this we have :

$$\Delta A_0 = c_b\mu_1\left[\frac{Wh_1}{2L} + \frac{B'(h_3 - h_b)}{l}\right]$$

$$+ P\mu_1\left(\frac{h_2}{2L} + \frac{h_3}{l}\right) \quad . \; . \quad (6)$$

The sudden starting to which goods waggons are usually subjected because of the coupling slack, results in high rates of acceleration and consequently weight transfer from rear to front bogies and from rear to front wheels. Observations in service have shown that such shock loads frequently assume the magnitude of 0.4 t. per t. of vehicle weight. If the accelerating (shock) force per unit weight is designated at t_a, then with reference to Fig. 3 the load upon the rear axle of the rear bogie will be decreased by the amount

$$\Delta A_0' = \frac{t_a \cdot B'(h_3 - h_b)}{l} \quad . \; . \quad (7)$$

In addition to accelerating the vehicle per *se*, the available force must also impart a rotary motion to the wheels and axle assembly. The moment of rotative

inertia of the latter will obviously tend to oppose the acceleration of both car and wheels and thus tend to help the forces bent to cause slide flat spots.

The moment of rotative inertia is located at the distance r_i^2 from the wheel axis (Fig. 4) this being given by the relation :

$$r_i^2 = \frac{I_\omega}{M_\omega} = \frac{I_\omega \cdot g}{W_\omega}$$

where :

I_ω = Moment of inertia of wheel and axle assembly with respect to the axis of rotation.

M_ω = Mass of the wheel and axle assembly.

W_ω = Weight of wheel and axle assembly.

g = Gravitational acceleration.

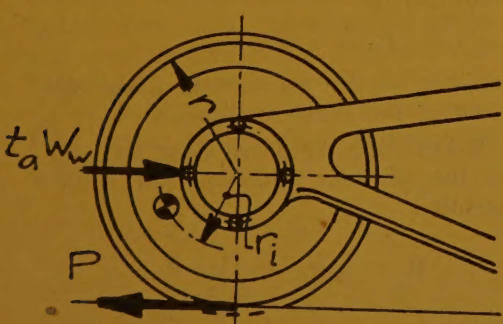

Fig. 4. — Forces at a wheel.

It is assumed that the mass of the wheel is concentrated at the distance r_i from the centre. At this point, which is moving at a rotational velocity v, is acting the force of inertia $M \frac{dv_0}{dt}$ which is opposed by the frictional force between rail and wheel so that

$$Mr_i \frac{dv_0}{dt} = P'r \quad . \ . \ (8)$$

Since $v_0 = \omega r_i$ we can write

$$Mr_i^2 \frac{d\omega}{dt} = P'r \quad . \ . \ . \ (8a)$$

However the assembly is accelerated by the force $t_a W_\omega$ not only rotationally but translatory as well and because of this we can write the differential equation

$$M \frac{dv}{dt} = t_a W_\omega - P'$$

and since $v = \omega r$:

$$Mr \frac{d\omega}{dt} = t_a W_\omega - P' \quad . \ (9)$$

From equation (8a) and (9) the magnitude of P′ can be determined by multiplying equation (8a) with r_i^2 and (9) with r and subtracting :

$$Mr_i^2 r \frac{d\omega}{dt} = t_a W_\omega r_i^2 P' r_i^2$$

$$- \quad Mr_i^2 r \frac{d\omega}{dt} = P' r^2$$

$$0 = t_a W_\omega r_i^2 - P' r_i^2 - P' r^2$$

or rewriting :

$$P'(r_i^2 + r^2) = t_a W_\omega r_i^2$$

and consequently

$$P' = \frac{t_a W_\omega r_i^2}{r_i^2 + r^2} \quad . \ . \ . \ (10)$$

The rotation of the wheels is also opposed by the viscosity of the lubricant at the journals. With plain bearings the coefficient of friction amounts to about 0.06 when starting after stopping the train for about 10 min. At very low temperatures this value may even rise to 0.08, whilst values of up to 0.1 were encountered after stops extending over 20 minutes. Assuming an average journal/wheel diameter ratio of 0.125 and the

coefficient of journal friction as 0.08, the tractive resistance at the wheel rim due to this cause will be

$$\alpha_1 = 1\,000 \cdot 0.125 \cdot 0.08 (A_0 - W_\omega)$$
$$= 10 (A_0 - W_\omega) \text{ [kgr./t.]} \quad . \ (11)$$

Another factor tending to oppose the motion of wheels is the rolling resistance. The values stated for this by various authorities are at considerable variance. Here we assume the value of rolling resistance at the start to 1 kgr. per ton, so that

$$\alpha_2 = 1 \cdot A_0 \text{ [kgr./t.]} \quad . \ . \ (12)$$

The most important single factor conductive to the origination of slide flats is that contributed by the inefficiency of the brake rigging. The efficiency of the brake rigging can be easily calculated (8) on the basis of certain assumptions, and for double bogie vehicles incorporating clasp brakes may be as high as 85 %, but in actual practice, particularly where goods waggons are concerned, values of 60 % are often encountered. Both the above values apply to stationary vehicles, i.e. static efficiency. For brakes applied or released whilst the vehicles are in motion higher (kinetic) efficiency values are the rule because of the effect of vibration on the rigging which results in increasing the overall efficiency to about 90 %.

Introducing :

P_1 = Total pressure maintained by the brake blocks.

F = Effective area of brake cylinder piston.

ρ_1 = Air pressure in brake cylinder

X = Leaverage of brake rigging.

η_k = Efficiency (kinetic) of brake rigging.

we can write :

$$P_1 = \eta_k \cdot F \cdot \rho_1 \cdot X$$

If now the brakes are released with the train stationary, and for some reason the cylinder pressure reduced to ρ_2 than :

$$\eta_s \cdot P_2 = \eta_k \cdot F \cdot \rho_2 \cdot X$$

where η_s = Efficiency (static) of brake rigging.

With the maximum brake block pressure of P_m and $P_2/P_m = y$ we have :

$$P_m \cdot y = \frac{\eta_k}{\eta_s} F \cdot \rho_2 \cdot X$$

and

$$y = \frac{\eta_k \cdot F \cdot \rho_2 \cdot X}{\eta_s P_m}$$

For a full brake application with the train moving :

$$P_m = \eta_k \cdot F \cdot \rho \cdot X$$

where ρ = Air pressure in brake cylinder at full brake application.

Substituting the above value for P_m in the previous equation and consequently :

$$P_2 = y \cdot P_m = \frac{\rho_2}{\eta_s \cdot \rho} \cdot P_m$$

whilst the retarding force applied at the wheel rim is expressed by

$$P_2 \mu_1 = \frac{\rho_2}{\eta_s \cdot \rho} \cdot P_m \mu_1 \quad . \ . \ . \ (13)$$

The above equation shows the effect of the losses encountered in the brake leaver system, and resulting in the brake forces being higher (at the same air pressures) when releasing the air from the cylinders of a stationary train, then when applying it with the train in motion. This apparent discrepancy is caused by the dif-

ference between η_s and η_k as evident by considering that if during application with $\eta = \eta_k$ and an air pressure value in the brake cylinder of ρ_1 we shall obtain a certain brake block pressure of P_1, when releasing the brakes the air pressure will have to be reduced to a value of ρ_2 (at $\eta = \eta_s$) before we shall have a brake block pressure of P_1, or in other words :

$$\eta_k \cdot \frac{\rho_1}{\rho} \cdot y = P_1 = \frac{1}{\eta_s} \cdot \frac{\rho_2}{\rho} \cdot y$$

The opinions as to the values of η_s and η_k vary widely and the results of tests carried out to determine these values are but few. Generally η_k is assumed to vary between 0.9 and 1, whilst the values of η_s depend very much upon the type of rigging and vehicle, passenger carriages having the benefit or better maintenance, more liberal use of grease and consequently lower η_s values. With waggons η_s scarcely exceeds 0.7 whilst η_k can be assumed to 0.95. Substituting these values in the above equation we obtain :

$$0.95 \cdot \frac{\rho_1}{\rho} \cdot y = 1.43 \cdot \frac{\rho_2}{\rho} \cdot y$$

and

$$\rho_2 = 0.667 \; \rho_1$$

This means that when releasing the brakes of a stationary train the brake block pressure will not be reduced until the air pressure is reduced to 66.7 % of the value originally applied whilst the train was in motion, this dependence being indicated in Fig. 5.

Finally the locking of wheels is facilitated by load transfer, or more precisely by the unloading of the rearmost axle if the brake blocks are not completely released when starting. If the pressure in the cylinder at the moment of start is ρ_2 then the brake power applied to the two axles of one bogie will be :

$$2k = \frac{2\rho_2}{\eta_s \cdot \rho} \cdot P_m \cdot \mu_1$$

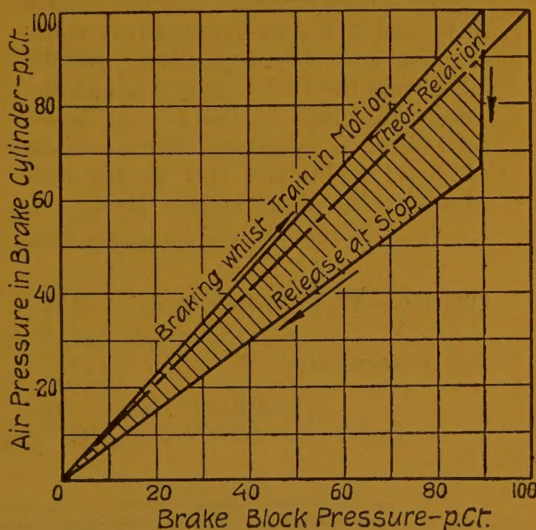

Fig. 5. — The effect of brake rigging efficiency upon its performance.

This force is applied at the point of contact between rail and wheels, and tends to turn the bogie by virtue of the momentum :

$$M = 2k \cdot h_b$$

unloading the rear axle by the amount

$$\Delta A''_0 = 2k \frac{h_b}{l} \quad . \quad . \quad . \; (14)$$

Having thus determined the magnitude of the various factors tending to lock the wheels of carriages upon start it is now possible to ascertain the sum total of forces acting in this direction, or — what is even more important — the minimum value of air pressure in the

brake cylinder which would be sufficient to lock the wheels when starting.

The locking of wheels is opposed by the force tending to produce a rolling motion. This force is determined by the axle load A_0 and the coefficient of friction μ between rail and wheels. The former is however reduced by the amount $\Delta A_0'$ and $\Delta A_0''$ as expressed by equation (7) and (14) respectively. On the other hand the forces tending to lock the wheels are given by the sum of forces determined in accordance with equations (10), (11), (12) and (13) so that with wheel locking about to take place :

$$(A_0 - \Delta A_0' - \Delta A_0'')\mu - P' - \alpha_1 - \alpha_2 - P_2\mu_1 = 0 \quad . \quad . \quad (15)$$

To indicate the magnitude of the minimum air pressure sufficient to lock the wheel consider the forces applied to the wheels of a goods car, the main dimensions of which are given in Fig. 6. For this we will have — with $t_a = 0.4$ — $\Delta A_0' = 176$ kgr., whilst

$\Delta A_0'' = 1.34 \frac{\rho_2}{\rho_1} P_m\mu_1$ and $P' = 123$ kgr.

Assuming $\eta_s = 0.7$ and $\eta_k = 0.95$ and introducing the above values in equation (15) we can write :

$$1\,000A_0\mu - 176\mu - 1.34\frac{\rho_2}{\rho_1}P_m\mu\mu_1 - 123 - 10(A_0 - W_w) - A_0 - 1.43\frac{\rho_2}{\rho}P_m\mu_1 = 0$$

and consequently :

$$\rho_2 = \frac{[(1\,000A_0 - 176)\mu - 123 - 10(A_0 - W_w) - A_0]\rho}{(1.34\mu + 1.43)P_m\mu} \quad . \quad . \quad . \quad . \quad (16)$$

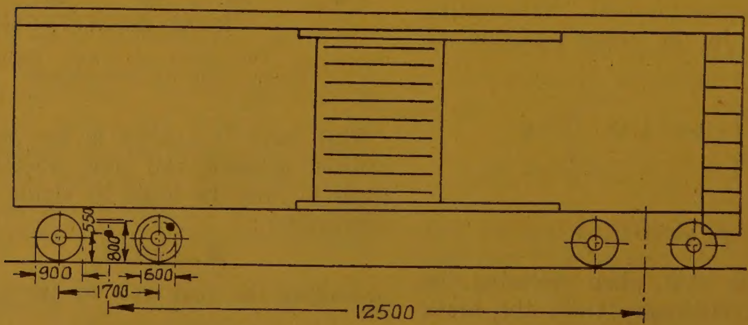

Fig. 6. — A typical waggon.

If now the brake ratio of the empty vehicle is limited to 80 % the equivalent air pressure in the brake cylinder being $\rho = 3.5$ atm., whilst the air pressure with the car laden is limited to 5.5 atm. so that $P_m = 4\,000$ kgr. and 6 500 kgr. respectively and assuming at very low temperatures $\mu = 0.2$ and $\mu_1 = 0.4$ then the resultant values of ρ_2 can be estimated and the results are plotted as a function of the axle load A_0 in Fig. 7.

The point which clearly emerges from Fig. 7 is that the wheels will be induced to slide more readily when starting empty

cars, a fact amply confirmed by practical experience. Equation (16) shows that all other things being equal the residual pressure ρ_2 sufficient to cause wheel slide is proportional to the maximum air pressure ρ so that the lower the maximum operating pressure of the system, and the greater the area of the brake cylinder or the total leaverage of the brake rigging, the easier it will be to cause wheel sliding.

It is of interest to ascertain under what conditions it will be impossible to stop wheel sliding even with completely released brakes. As indicated in Fig. 1 the value of the coefficient of friction between rail and sliding wheel drops rapidly as the speed increases to about 20 km./h., so that at higher speeds two factors tend to keep the wheel sliding; the reduced value of μ and the increasing area of the flat spot developed as the result of sliding. Observations have indicated that the depth of flat spots is usually generated at the mean rate of about 1 mm. per km. of sliding. With reference to Fig. 8 it will not be possible for the wheel to resume rotation — even with fully released brakes — if :

$$\mu A_0(r - X) = A_0 s$$

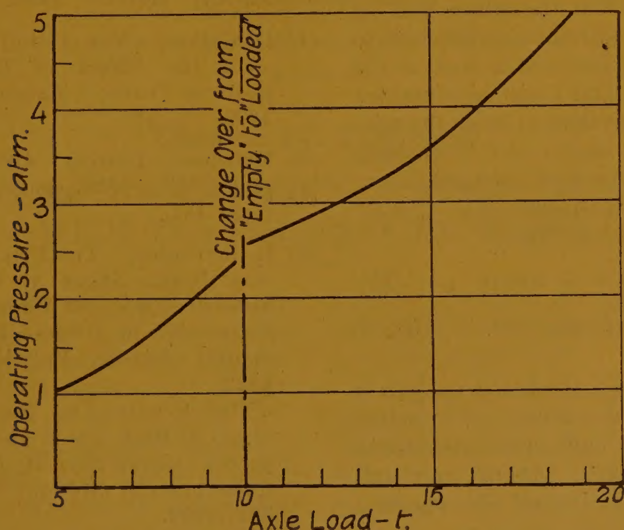

Fig. 7. — Wheel locking pressure versus axle load.

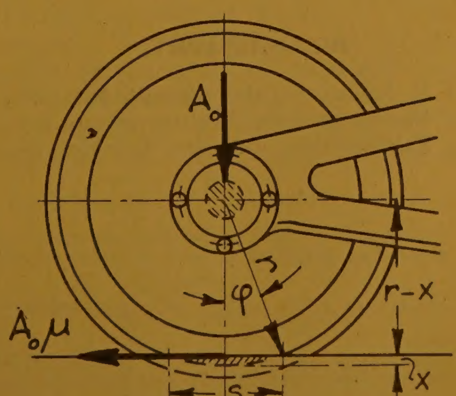

Fig. 8. — Forces acting on a sliding wheel.

Since :

$$s = (r - X) \tan \varphi$$

we can write :

$$\mu A_0 (r - X) = A_0 (r - X) \tan \varphi$$

and :

$$\mu = \tan \varphi$$

This indicates that the wheel will be in a condition of unstable equilibrium so far as sliding is concerned as soon as the length of the flat spot s will be contained within an arc equivalent to twice the friction angle. Assuming $\mu = 0.15$ unstable equilibrium will be attained with $\tan \varphi = 0.15$. This corresponds to $\varphi = 8°30'$ and $\cos \varphi = 0.989$ so that

$$X = (1 - 0.989) r = 0.011 r \quad . \quad . \quad (17)$$

In the case of the wheels Fig. 6, $X = 5$ mm.

The above values are based on purely theoretical considerations. In actual practice the jolts and jerks experienced by the wheels when passing over rail joints will tend to impart the wheels a rotary motion.

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[621 .337]

Individual axle drive.

Mechanical systems used on electric locomotives and railcars, with an indication of the results obtained in service on railways of all kinds,

(Continued)*

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Chapter IV. *(Continued)*

DRIVING MECHANISM USING SPRINGS (OR RUBBER) WITH TRANSMISSION BY GEARS.

We have already considered (see under fig. 126) the behaviour of this arrangement on « M » type locomotives (fig 123) of the Swedish SJ Railways [76], which have an axle load of 17 tons only.

The French Diesel-electric super-locomotive (No. 262 AD-1, SNCF, noted at the side of fig. 127) has an even smaller axle-loading, 16 tons in working order, and as regards its push-rod mechanism (figs. 122, 124-126) is satisfactory (current maintenance being confined to lubrication every 6 000 km. [3 728 miles]); it will be further discussed in the Appendix at the conclusion of this series [77].

As regards the behaviour of this flexible push-rod transmission on the locomotives $Ae^6/_8$, Nos. 207 and 208 (see figs. 44, 127-128) of the BLS (Bernese Alps), it can be stated that :

In spite of the heavier — 20 tons — axle load (which is general for heavy locomotives on main-line working in Switzerland) no breakages have been experienced by the BLS., either of the springs or of the push-rods. Whilst the Motive Power Department, however, has experienced a certain amount of wear on the rubbing parts of the boxes [78] and considers that the specific load of the points of contact of the push-rods and the corresponding sockets is high and consequently gives rise to certain difficulties in lubrication (which is done at

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(*) See *Bulletin of the International Railway Congress Association*, Nos. of September, October and December 1947, pp. 823, 885 and 999 respectively, Nos. of February and April 1948, pp. 73 and 227 respectively.

([76]) See text above fig. 97, left-hand column. With regard to express « F » type locomotives of the SJ, see text to the right of fig. 91.

([77]) This locomotive works the same services as the similar No. 262. DB-1 locomotive, the axles of which have AEG-Kleinow (quill-cup) couplings, and this also will be mentioned in the Appendix.

([78]) See figs. 119 and 122, and the description on the pages with fig. 118, also figs. 121-122.

the Depot twice monthly), it is a fact that the mileage effected up to the end of 1947 was 743 000 km. (461 700 miles) with locomotive No. 207 and 557 000 km. (346 000 miles) with locomotive No. 208. The BLS Motive Power Dept. also considers the maintenance costs of the transmission elements of these locomotives are higher than those of the former Sécheron mechanism of locomotives Nos. 201-206 (see figs. 43 and 45) and has consequently decided to replace it by the Sécheron arrangement.

We shall, therefore, return to the various uses (SNCF, BLS and MAV — which follows) in the Appendix, in which the most recent applications will also be mentioned.

— In 1939 two locomotives 2-D_0-2, series V.44, 4 000 H.P. for max. speeds of 125 km./h. (78 m.p.h.) Hungarian State Railways (MAV — Magyar kir. Allamvasutak) [79]. These two locomotives are worked on the principle of single phase (50 and 82⅓ cycles) frequency conversion with a parallel three phase induction motor for traction for each driving axle. From the information which it has been possible to obtain since the end of the war, the first of these locomotives, provided with push-rod mechanism began its trials during the war in 1943. After about 2 000 km. (1 400 miles), it was sent to the Hungarian State Works in Budapest for examination. After about 4-5 000 km. (2 500-3 100 miles) trial running the locomotive was put into normal service without special technical supervision, for hauling various trains serving the retreat of the German army and was only returned to Budapest after the end of hostilities. As for the second

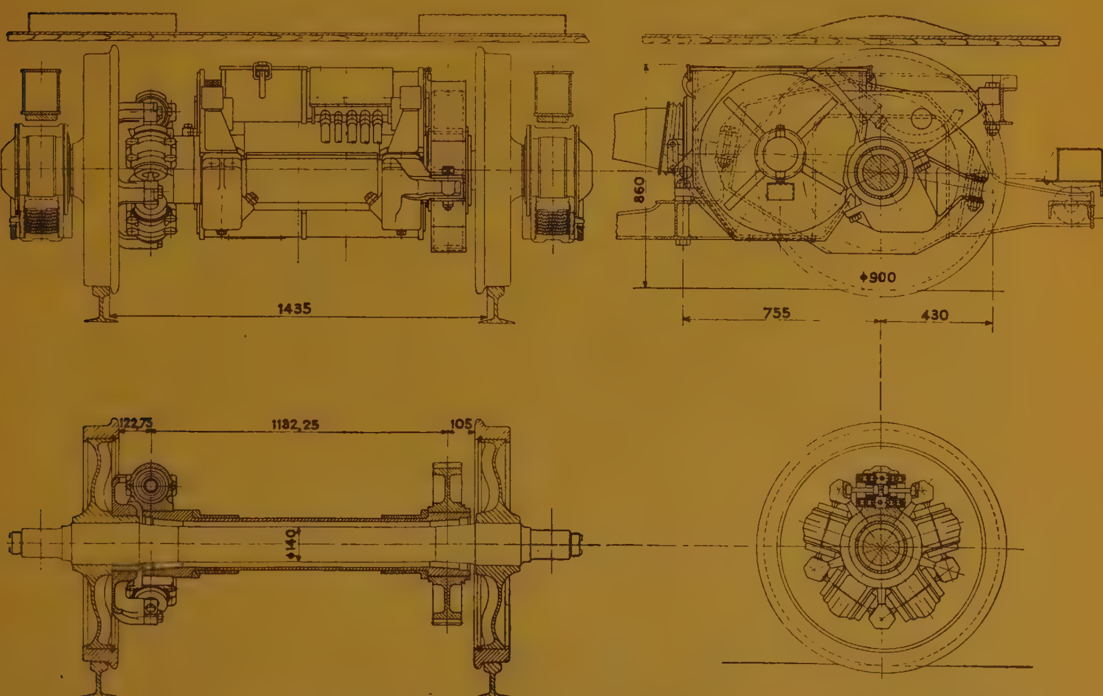
Fig. 129. — Double « Blue Arrow » set of the Lötschberg Railway, series 731 BLS (736-737 BN), on trial in 1937 at Frutigen.

[79] Kir = royal, since dropped, but the initials remain unchanged.

locomotive, it was destroyed as a result of war damage before the construction was even completed.

It has already been stated that the push-rod mechanism had been used either in a heavy construction (with components mounted between wheel spokes) for *locomotives*, or in a lighter construction (inside the wheel centres) for *railcars*. We now come to the description of the railcar push-rod mechanism.

In 1938, motor-driven stock (railcars and trailers) which will be detailed below, called the « Blue Arrow » and « Blue Train » respectively, for the Lötschberg Railway (BLS — Bernese Alps) were fitted with this push-rod mechanism, which was replaced in 1945/6 because of the high maintenance costs by a Sécheron coupling with oil-bath spring guide boxes. This latter arrangement has a hollow shaft with blocks integral with the motor body. The hollow shaft has a gear wheel at one end which engages with a pinion on the motor shaft, and at the opposite end there is a circular support for the guide boxes. Arms, which are solid with the wheel, engage in the spring boxes in the same way as in the Brown-Boveri mechanism with guide boxes, described later. In view of the similarity, illustrations of the Sécheron coupling are not reproduc-



Cliché Sécheron.

Fig. 130. — Complete driving axle, front view, elevation and sections, of the BLS sets, in figs. 129, 131-133, shewing the arrangement of the Meyfarth-Sécheron push-rod mechanism for railcars.

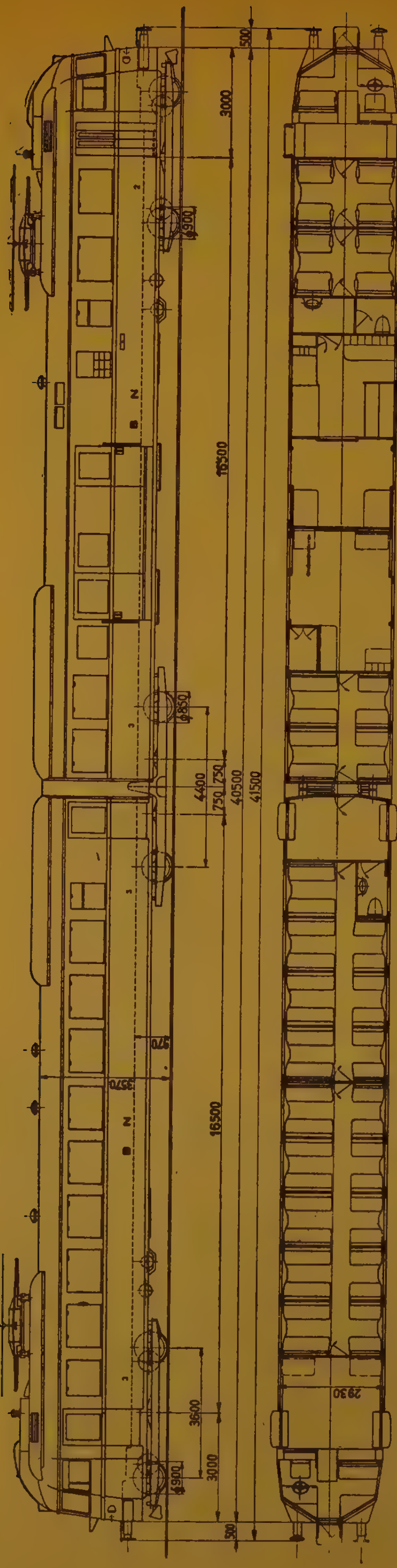


Fig. 131. — Elevation and plan of the 2-unit, 3-bogie, articulated sets (fig. 129, since converted) (BLS). This set embodies radial axles, Leichty-VRL-SJG system, the centre bogie being separable, in two parts, to provide for depot needs or replacement.

ed, reference being made to the fig. 146 and following figs. as necessary. These arrangements are enclosed in an oil-bath, lubrication is perfect and wear is kept within normal limits. However, as this Sécheron housing has two parts — one for the gears and one for the mechanism — it is only suitable for normal-gauge railcars of limited power [80].

These original « blue » railcar sets, first provided with push-rod mechanism and radial-axle bogies, were :

— 3 railcar sets, type BCFZe$^4/_6$ (articulated sets on three bogies) Nos. 731 (BLS) and 736-737 (BN — Berne-Neuchâtel direct line operated by the BLS), shewn in figs. 129 and 131.

— 2 motor coaches with four axles, type Ce$^2/_4$, Nos. 706 and 691 [81] for the Spiez - Erlenbach - Zweisimmen and Gürbetalbahn lines respectively.

The 3 *new* railcar sets BCFe$^4/_8$, Nos. 741, 742 and 743 of the BLS with four bogies — the two central bogies driving — will be discussed later when dealing with spring guide box mechanism of Brown-Boveri design. These sets were originally fitted with Sécheron mechanism with two oil-bath housings as mentioned above [82].

All these railcars were built for maximum operating speeds of 110 km./h. (68 m.p.h.). The maximum gradients on the

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[80] See *Revue Polytechnique Suisse (SBZ)*, Zurich, 28th June 1947, p. 363, middle of right-hand column.

[81] These two motor coaches are actually designated as type BCFe$^2/_8$, Nos. 702 and 704, as they have been permanently coupled to trailers of the same type and no longer run singly [reversible sets, described in p. 15 of the publication mentioned in note [82]].

[82] See *Bulletin Sécheron*, Geneva, No. 18, 1946, pp. 9-14 (H. WERZ).

various lines vary between 18 and 27 ‰ (35 ‰ on the Schwarzenburg line). Fig. 130 shews a complete axle of the railcar set shewn in figs 129 and 131. rying bogie (which can be divided to allow repair of one-half of the unit). These sets have been described in various articles in the technical journals [83].

Cliché Liechty (VRL-SJG).

Fig. 132. — One of the forward driving bogies of the sets in figs. 129 and 131. As in fig 133, the individual chassis for each radial axle can be seen within the main bogie frame.

Figs. 132 and 133 shew respectively one of the end bogies (with the push-rod driving mechanism) and the interior carrying bogie. The driving mechanism of the two light BLS railcars with two bogies, mentioned above and in the second place numbered

(83) See *Economie et Technique des Transports* (formerly l'*Allégement dans les Transports*), Lucerne, vol. 3-4, 1937, pp. 44-45. — *Bulletin of the International Railway Congress Association*, Brussels, Oct. 1937, pp. 2330-2331, L. LEYVRAZ. — *Neue Zürcher Zeitung* (Beiblatt Technik), 22/12/1937, Zurich, « Blaue Doppelpfeile ». — *La Traction Electrique*, Besançon, Nos. 1-6, 1938, pp. 3, 13, 19, 23-24. — *Bulletin of the International Railway Congress Association*, Brussels, Feb. 1939, pp. 95-117, [also dealing with the articulated railcar $CFZe^2/_6$, No. 681 of the BSB, Berne-Schwarzenburg, see note (84)]. — *Elektrische Bahnen*, Berlin-Munich, June 1939, « Die elektrischen Leichttriebzüge der Lötschbergbahn », H. WERZ, pp. 155-160. — *Bulletin Sécheron*, Geneva, No. 11, 1939, pp. 21-29 (15 figs., plans and diagram).

702 (SEZ) and No. 704 (GBS) [84] are similar (fig. 130) [85].

Several of these railcar sets and motor coaches of the BLS-BN system were fitted with radial-axle bogies, to which we shall refer later.

— Another known use is that on one of the red, three-unit, railcar sets of the Swiss Federal, SBB-CFF, type $Re^8/_{12}$, No. 691 [formerly $RBCFe^8/_{12}$, No. 502 [86], 1937, with six bogies, of which four were driving (on the two leading vehicles)]. See figs. 134 to 139.

These sets have been described in various technical journals [87] and they are shewn complete, in fig. 134, with a half set in plan and elevation in fig. 135. Fig. 136 shews a driving bogie fitted with push-rod mechanism for railcars and figs. 137 to 139 the complete axle, with motor on the hollow shaft, and details of the mechanism assembled.

On the triple set $BCFZe^8/_{12}$, No. 502, put into service in 1937, and which has now been re-designated $Re^8/_{12}$, No. 691, this push-rod mechanism has been retained. Meyfarth-Sécheron push-rod mechanism, for flexible transmission, was fitted on the eight driving axles of this set No. 502, but since the beginning of

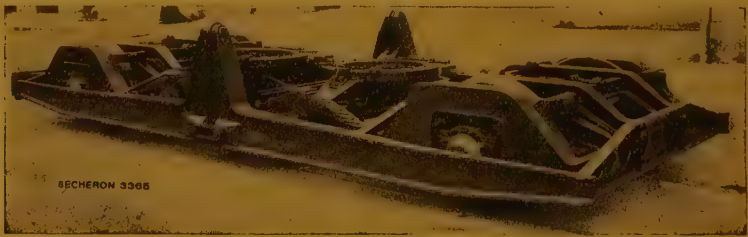

Fig. 133. — Central bogie, non-driving, for articulation of set in figs 129 and 131. The central joint to permit separation can be seen.

(84) See *Bulletin of the International Railway Congress Association*, Brussels, Oct. 1937, p. 2320 and following. — The new GBS (Gürbetal-Berne-Schwarzenburg) grouping was created by the amalgation, in 1945, of the « Gürbetalbahn » GTB and the « Bern-Schwarzenburg-Bahn » BSB.

(85) See *Bulletin of the International Railway Congress Association*, Brussels, Oct. 1937, pp. 2319-2331, L. LEYVRAZ†, Chief Engineer of Motive Power, BLS, « Light railcars, series $Ce^2/_4$, Bernese Alps Railway ». — *Economie et Technique des Transports* (formerly l'*Allégement dans les Transports)*, Lucerne, vol. 5-6, 1936, pp. 58-62 (same title and author) and 3-4, 1938, pp. 30-31 (article by Ing. Ad.-M. HUG).

(86) Set No. 501, of the same series, with Oerlikon mechanism, which will be dealt with later, was damaged by fire at the Rorschach depot during the war and was converted to a two-unit set $Re^4/_8$, No. 311, with four bogies, the two outer ones driving, and a single pantograph; the number of the series was recently changed from 311 to 671.

(87) See *Bulletin CFF*, Berne, No. 7, pp. 102-107, article by F. STEINER of the CFF, and No. 12 (p. 185) of 1937. — *La Traction Electrique*, Besançon, No. 1-6, 1938, pp. 17-19, article by W. MÜLLER of the CFF. — From the same author : *Revue Polytechnique Suisse SBZ*, Zurich, 1938-I, p. 125, and *Elektrische Bahnen*, Berlin-Munich, 1938, p. 69. — *Elektrische Bahnen*, Berlin-Munich, March, 1938, « Die Schnelltriebzüge der Schweizerischen Bundesbahnen ». F. STEINER, CFF (11 p., 21 figs., plans and diagrams). — *Schweizerische Bauzeitung SBZ*, Zurich, 15 July, 1939, « Der Doppelschnelltriebwagen $Re^4/_8$, No. 301, der SBB », by the same author, pp. 27-32 (11 figs. and diagrams). — etc.

Fig. 134. — 3-unit, 6-bogie rail car set, type BCFZe$^{8}/_{12}$, Nos. 501 and 502 (renumbered Re$^{4}/_{8}$, No. 311, then 671 and Re$^{8}/_{12}$, No. 691 respectively), Swiss Federal Railways, fitted with Oerlikon (« Federtopfantrieb ») and Meyfarth-Sécheron push-rods respectively.

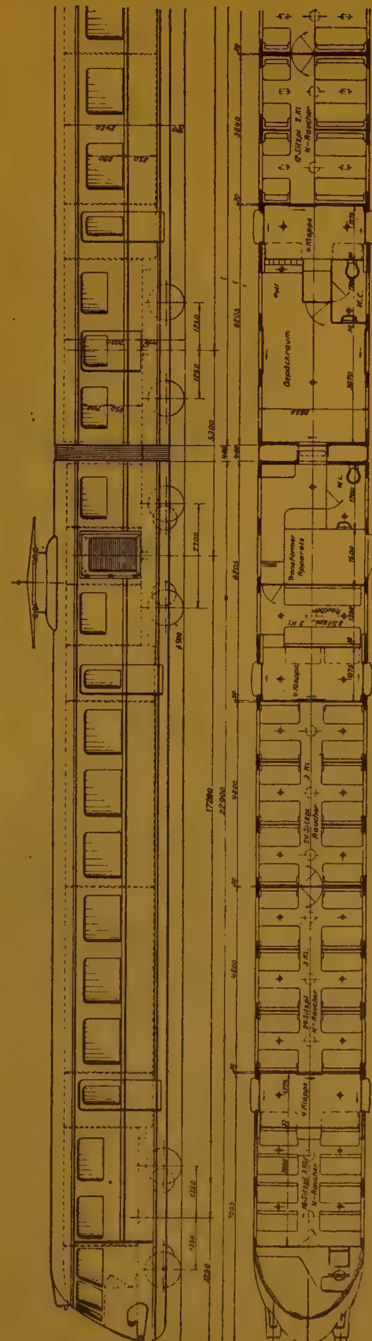

Fig. 135. — Elevation and plan of half-set, fig. 134.

1948 one of the eight driving axles has been fitted experimentally with the 1939 Sécheron arrangement using spiral springs, which will be described at the end of this Chapter under single or experimental applications.

Fig. 136. — First driving bogie of set in figs. 134 and 135.

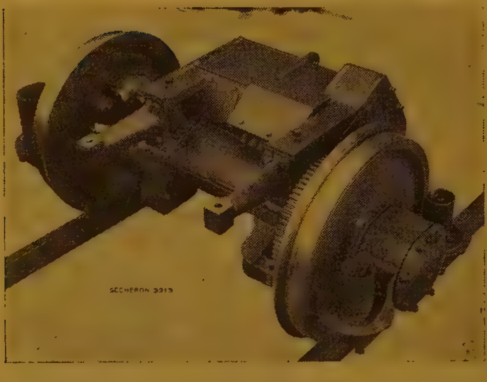

Fig. 137. — A driving axle of set in figs. 134 and 135.

During the ten years in which set No. 502 has been in service, the behaviour of the push-rod mechanism has been similar to those fitted to the BLS motor vehicles already mentioned. There has been heavy wear of the spring supporting sleeves (up to 2mm. [$^5/_{64}$"] in depth, or about 4 mm. [$^5/_{32}$"] in diameter) on the bearing plates of the push-rods, and on the push-rods themselves, with occasional breakages of the latter. It has actually occurred, that on arrival of the set in the shops for overhaul several push-rods were missing (presumably lost after breakage) without this fact causing any difficulty in service or the loss being noticed; this latter happening may in certain respects be regarded as a point in favour of the mechanism. Finally, cracks have appeared in the hollow shaft, probably on account of the violent effect of excentricity following wear.

To compensate for wear of the parts — the push-rods were shortened by hammer-blow by an average of 3 mm. ($^1/_8$") (which is doubled, to 6 mm. [$^{15}/_{64}$"] in each transmission unit) — the CFF workshops treated the metal by « noroxidisation » (neutralising) of the outer cylindrical surface of the sleeves concerned,

to restore them to the original diameter [88]. To compensate for the shortening of the push-rods, the push-rod supporting cup has so far been raised 3 mm. (using the packing pieces shewn in fig. 140). The wear on the cups in question, the bottom of which is normally flat, has consisted on the one hand in a saucer-shaped widening in the bottom, and on the other hand on the inside of the rim and always on one side only, in a widening caused by the lateral batter of the push-rod heads. The Author believes that it would have been better if the bottom of the cups, instead of being plain had been shaped as a concave cap with a radius a little larger than that of the convex push-rod heads; this would result in lower specific local loads and the heads of the rods would be better located so far as lateral batter is concerned.

When returned to service after overhaul at the beginning of 1948, the CFF set in question, No. 691, had the push-rods and cups replaced by new parts, similar to the original ones and the bronze bearings, instead of covering only the outer 180° (half the sleeve), were extended to the whole circumference of the sleeve (360°). Fig. 141 shews the

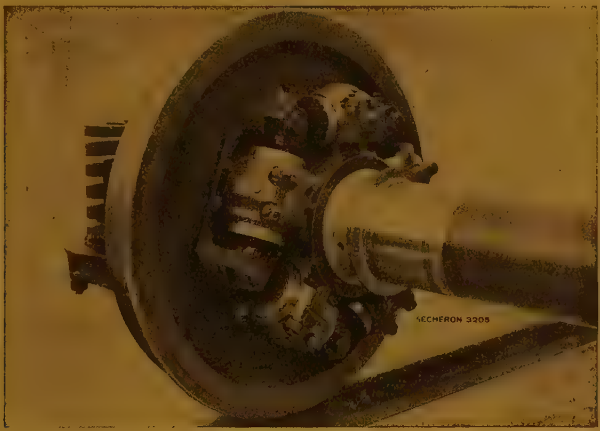

Fig. 138. — Part of driving axle, fig. 130, shewing the Meyfarth-Sécheron railcar mechanism mounted on the hollow shaft.

Fig. 139. — Details of mechanism in fig. 138, partly dismantled (see fig. 130).

(88) New toraxisation process, with which the Roll Works (Switzerland) state they deal with steel; with other processes only chrome or nickel can be treated.

arrangement of the two half sleeves. The CFF is retaining this mechanism on the set, with the small improvements described.

— Finally, this mechanism was fitted to one railcar, put into service in 1938, type CFe$^2/_4$, No. 101 (fig. 142), of the « Sensetalbahn » — a local railway serving the Singine valley, Flammatt-Laupen-Gümmenen, in Switzerland. This car is 450 H.P. (one driving and one carrying bogie) and its maximum operating speed is 60 km./h. (37 m. p.h.).

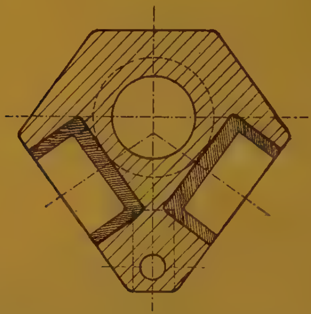

Fig. 140. — Meyfarth-Sécheron packing piece, shewing the socket and liner for the push-rod heads.

The Management of the Railway has been satisfied with the car and its mechanism (oil change every three months) and propose to order a similar one, to be No. 102.

In connection with the study of this flexible push-rod transmission (in German « federnder Stösselantrieb ») the Sécheron Co. will decide on future uses, having regard to the development of the new tendency to build locomotives with a total adhesive weight, with bogies and small wheel diameters and taking into account their new construction (leaf-spring coupling) which will be dealt with in Chapter VII.

Oerlikon flexible transmission.

We have already mentioned the light, express, triple railcar set Re$^8/_{12}$, No. 691 (formerly No. 502) of the Swiss Federal, SBB-CFF (figs. 134 and 135). A similar set, No. 501, later No. 311 and now a double set, type Re$^4/_8$, No. 671 [89] has an Oerlikon mechanism, introduced at the same time (1937). Fig. 143 shews this mechanism fitted to an axle in a driving bogie of No. 501 (No. 671, fig. 134); it will be seen that it is very similar to the quill cup drive : apart from the push rods there is also a similarity in the central part to the supporting cylinders of the mechanism we have just described. Moreover, it is also known as « Federtopfantrieb » and is constructed specially for high-speed railcars [90].

Fig. 141. — Intermediate support for spring (cf. figs. 130 and 138-140) 10 cm. ($3^{15}/_{16}''$) wide.

A = 180° bronze bearing (replaced by 360° bearing).
P = push-rod.
C = liner for holding push-rod head.
G = Tecalemit lubricator.

[89] Se note [86] and [87].

[90] See *Bulletin CFF*, Berne, July, 1937. — *Elektrische Bahnen*, Berlin and Munich, March, 1938.

It comprises a transmission with integral hollow shaft which carries the spring mechanism at one end, and at the other end is a gear wheel which engages the motor pinion (fig. 144). The essential feature is five coil springs, of square section, a description of which is given below :

A driving spider, mounted on the wheel centre, carries five driving pins of trian-

Cliché Sécheron.

Fig. 142. — Railcar No. 101, Sensetalbahn, Switzerland.

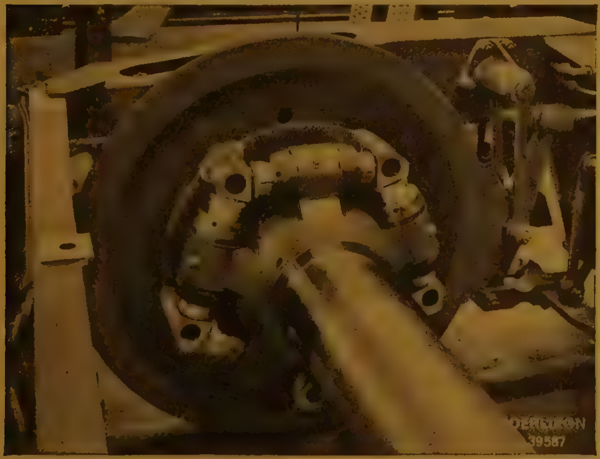

Fig. 143. — Oerlikon spring couple (cf. fig. 145) mounted (without motor) on hollow shaft and axle of set in figs. 134-135. Part of the frame and brake rigging can be seen.

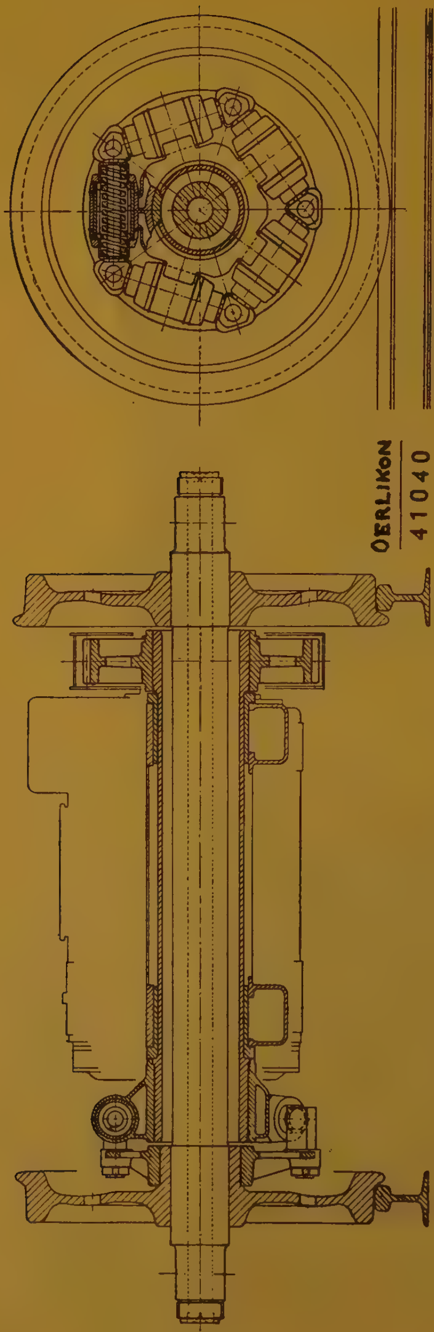

Fig. 144. — Elevation (part sectioned) and section through centre-line of axle — mechanism in fig. 143.

gular section (angle of faces 360°/5 = 720). These pins are uniformly spaced, with a diameter of approx. 537 mm. Corresponding to the driving spider of the wheel is the spring spider with five sockets to take the springs and cylinders. The cylinders are of steel and are set in the sockets of the spring spider. The square section spring is compressed between the two ends of the cylinders by two consecutive driving pins, triangular in shape. Transmission through the couple is, therefore, effected in both directions, by pressure on the springs from the triangular driving pins.

In order that such a transmission responds to all conditions of working at high speeds, first-class materials must be used in the construction. Both spring and driving spiders are of cast steel, all other parts being of steel or of special steel. The cylinder units for the springs are of drawn steel and not welded. The spring spider sockets have nickel-chrome liners. The bases of the cylinder units and the driving pins are of special crucible steel. Each socket is provided with a Tecalemit lubricator.

This flexible Oerlikon transmission, as originally provided for the express set mentioned, No. 501 and 671 (311) respectively, of the CFF, provides the following advantages :

1) The liners of the spring spider sockets are in one piece, providing an exact guide for the cylinders and wear and lubrication are reduced to a minimum;

2) The cylinder unit is made up of concentric cylinders, adjusted with precision. The spring works only under compression. The cylinder units are light

and all bearing surfaces are of ample proportions, which is very important on account of the centrifugal forces;

3) Lubrication with the Tecalemit lubricators is very simple. The general construction is so arranged that changes can be made *without dismantling either the axle or the motor;*

4) This flexible Oerlikon transmission is — as are the ones previously described and others which will be mentioned later — of small bulk (616 mm. [$2^{15}/_{64}''$] diameter and 220 mm. [$8^{11}/_{16}''$] width). Even with a maximum excentricity of 26 mm. ($1^{1}/_{32}''$) the cylinder units do not pass outside the driving spider circumference.

5) The transmission weighs only 258 kgr. (568 lbs.) per axle, including the hollow shaft, the latter weighing only 90 kgr. (198 lbs.) with an inner diameter of 240 mm. ($9^{7}/_{16}''$).

Fig. 145 shews a driving bogie with one of the two motors in position, the gearcase being removed. The exterior appearance of the converted set is similar to fig. 134 except that it now consists of only two vehicles and four bogies (instead of three and six).

Up to the present, there have not been any further applications of this mechanism. As regards its behaviour in service and cost of maintenance the Swiss Federal Railways consider that it is satisfactory.

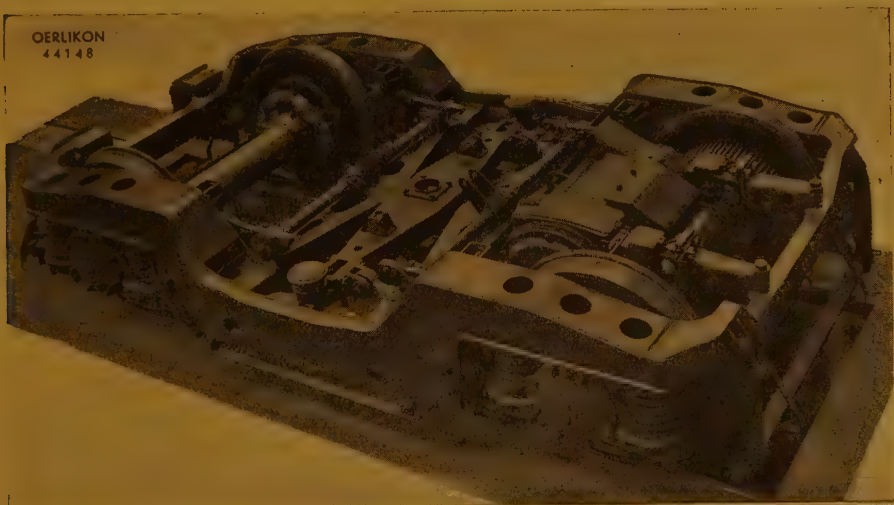

Fig. 145. — New bogie, with one motor and gearcases removed; set RBCFe$^{8}/_{12}$, No. 501, figs. 134-135, new designation Re$^{4}/_{8}$, No. 671 (311), shewing Oerlikon mechanism, figs. 143-144 (cf. fig. 136).

Brown-Boveri spring transmission with oil bath.

This mechanism also embodies the same basic principles as the quill cup drive (coil springs of round section,

housed in sliding couples on which operate arms attached to the wheel for the transmission of the motor couple) and is furthermore designed specially for railcars or locomotives with wheels of small diameter. It is specially constructed for high-speed services ([91]).

Fig. 146 shews diagrammatically the lay-out of the two arrangements for complete hollow shaft and for a short (stub) hollow shaft.

The mechanism may be described as follows (see figs. 146 and 150) :

On the stub 5 of the hollow shaft (or

1 : motor.
2 : pinion.
3 : large gear wheel.
3' : spring (round section) with 3 couples.
4 : driving arms fixed to axle.
5 : stub hollow shaft.
5' : hollow shaft full length of axle.
6 : axle.
6' : driving wheels.
7 : bogie frame (individual axle chassis for radial axles).
8 : gearcase.
9 : lubrication points.
α = centre line of axle.
β = centre line of motor.

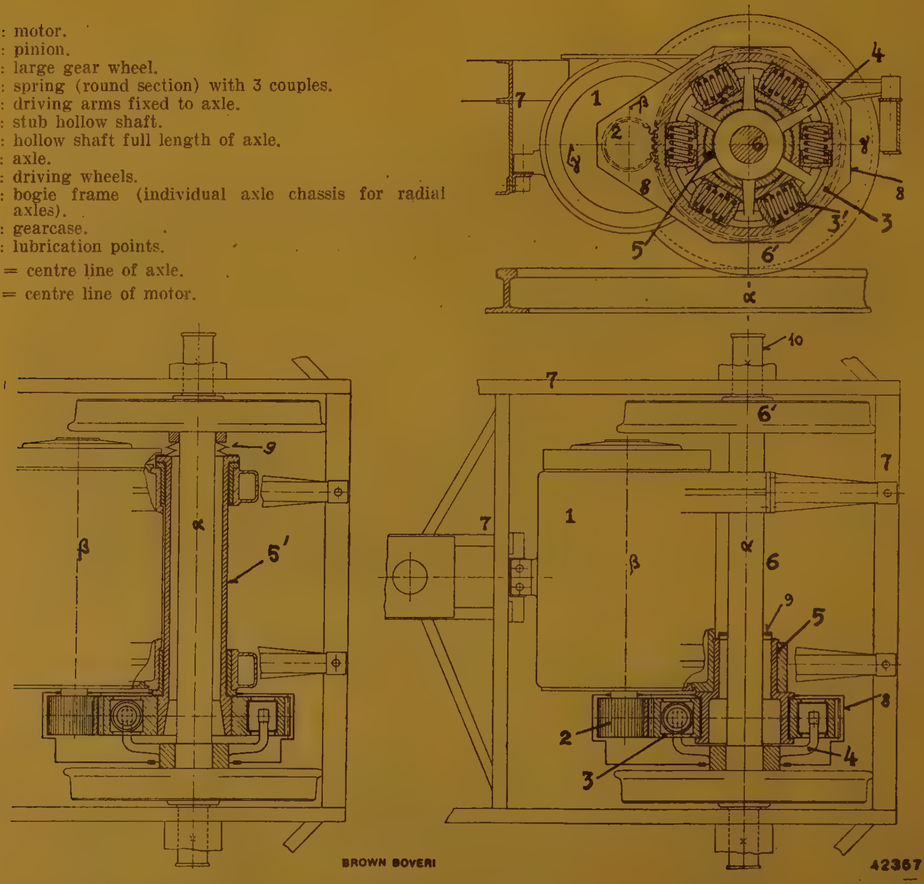

Fig. 146. — Diagram of Brown-Boveri springs and couples for railcars. The horizontal sections shew, left the complete hollow shaft and, right the short, stub, shaft (see also figs. 147-150).

([91]) See *Bulletin CFF*, Berne, Sept. 1935, pp. 160-162, with diagrams. — *Revue Brown-Boveri*, Baden (Switzerland), Aug. 1935. — *L'Allégement dans les Transports* (later *Economie et Technique des Transports*), Lucerne, vols. 5-6 and 11-12, 1935, pp. 69 and 153-154.

on the hollow shaft 5′ where this is arranged for the full length of the axle) is mounted the gear wheel 3, with the cylinder units (sleeves) containing the springs. In the space between the sleeves and resting on the sleeve heads at each side are the driving arms 4, fixed to the disc keyed to the axle shaft 6 itself. Between these driving arms and the spring sleeves is effected the relative movement between the axle and the chassis. The hollow shaft (or stub shaft) carries the fittings to which is attached (or on which rests) the motor. The operation is then similar to that of the flexible transmissions described above.

The applications of these arrangements, in chronological order of their being put into service, are as follows :

1) In 1933/35/36 successively, seven light express electric railcars, known as the « Flèches Rouges » (Red Arrows) ([92]), shewn in figs. 151 and 152 and providing 56 seats, 800 H.P., 125 km./h. (78 m.p.h.)

Cliché SBZ.

Fig. 147. — Part of railcar axle (CFF set $Re^4/_8$, No. 301, renumbered 651) shewing the mechanism in fig. 146 (l.h. side).

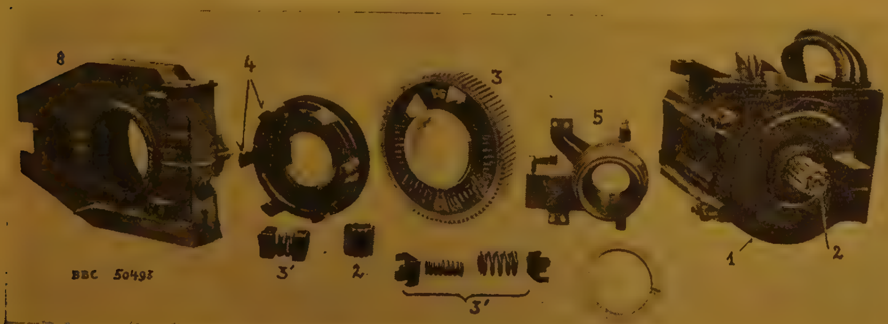

Fig. 148. — Brown-Boveri mechanism (figs. 146-147) with 200 H.P. motor (at 1 500 r.p.m.) of light express « Red Arrow » railcars of CFF (figs. 151-152, stub hollow shaft). The numbers refer to the parts shewn in fig. 146.

([92]) See : *Bulletin CFF*, Berne, July, 1934, and April, 1935. — *Organ für die Fortschritte des Eisenbahnwesens*, Berlin, vol. 12, 15th June, 1934, concerning Switzerland, F. STEINER, CFF. — *L'Allégement dans les Transports* (later *Economie et Technique des Transports*), Lucerne, vol. 9-10, 1934, pp. 120-121, No. 3-4, 1935, pp. 31 and 47-49, No. 1-2, 1938, pp. 10-12, Ad.-M. HUG. — *Revue Brown-Boveri*, Baden, Switzerland, Aug. 1935, pp. 151-157. — *Revue Polytechnique Suisse SBZ*, Zurich, 25 Jan. 1936.

Fig. 149. — Axle of BCe$^4/_4$ series railcars, Nos. 1-3, and BCe$^2/_4$, Nos. 11-12, of Swiss Yverdon-St. Croix Railway, shewing the transmission parts on the axle ready for mounting. Numbered as in figs. 146 and 148 (10 = axle journal).

(speed on trials 140 km./h. [87 m.p.h.]). These seven railcars are type CLe$^2/_4$, series 201-207 and were built by the Winterthur Locomotive Works SLM, as regards the mechanical parts and by Brown-Boveri, Oerlikon and Sécheron for the electrical equipment. They have one driving and one carrying bogie; the driving bogies of cars 203 to 207 are very similar to that in fig. 136. In 1944, the earlier cars were converted to haul loads of up to 30 tons and for this purpose have been fitted with normal buffing and draw gear, Westinghouse automatic brake

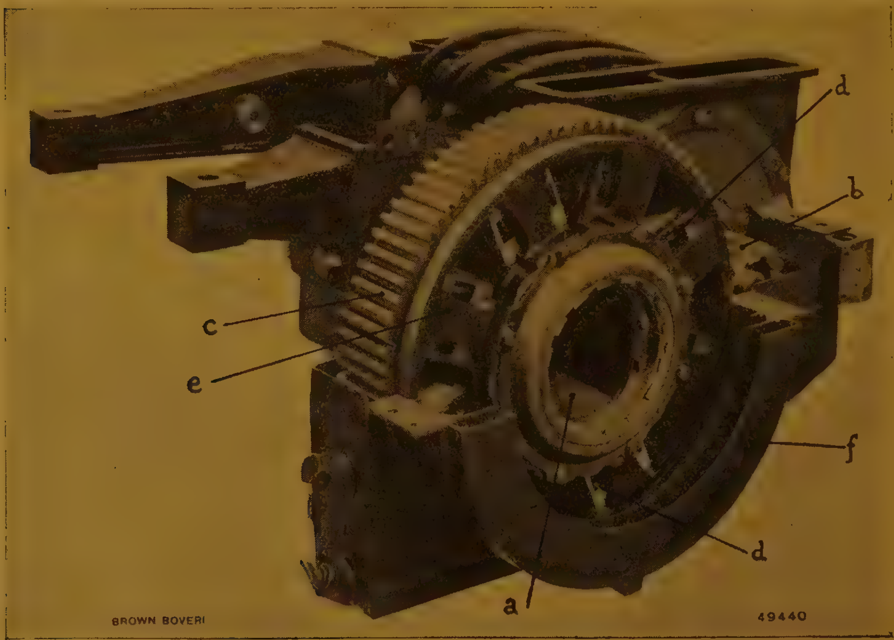

Fig. 150. — Motor with transmission mechanism (without axle driving arms) of Diesel-electric locomotives, type AM$^4/_4$, series 1001, CFF (see further the figures relating to these engines).

a : stub hollow shaft fitted to motor body.
b : pinion.
c : flexible gear wheel.
d : transmission springs in gear wheel.
e : gear wheel boxes for transmission springs.
f : gearcase with lubrication points.

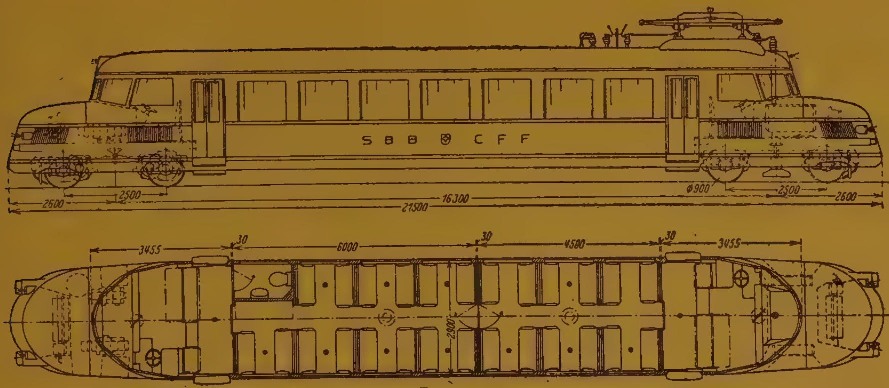

Fig. 151. — Dimensioned plan and elevation of « Red Arrow » railcars of CFF, type $CLe^2/_4$, series 201.

Fig. 152. — « Red Arrow » railcar CFF, fig. 151.

and a lead for the heating of the trailer (93).

2) In 1935, railcar No. 787, type $Ce^2/_4$, fig. 153, of the Bernese Alps BLS, with two bogies, each with one motor but with radial axles, i.e. controlled so as to be set radially to curves. These will be dealt with later under bogies with radial axles. See previous figs. 129, 131, 132, 133 and 146.

3) In 1936/37, the German Reichsbahn put into service four Diesel-electric railcar sets, two of which had four cars (94) and two had three cars, each set including two motor coaches with two driving axles (95).

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(93) See *Bulletin CFF*, June, 1944, pp. 96-97, 3 figs.

(94) See : *Organ für die Fortschritte des Eisenbahnwesens*, 1st Dec. 1937, « Neue vierteilige dieselelektrische Schnelltriebwagen der Deutschen Reichsbahn », N. BREUER, D.R., 9 p., 15 figs. and plans, 3 tables. — By the same author : *Railway Gazette*, London, 1938-I, p. 336, and 1938-II, p. 434; *Glasers Annalen*, Berlin, 1938-I, p. 52; *Motortechnische Zeitschrift*, Stuttgart, 1940, p. 194.

(95) See *Organ für die Fortschritte des Eisenbahnwesens*, 1938, p. 421, « Die dreiteiligen Schnelltriebwagen Bauart Köln der Deutschen Reichsbahn », ZIELKE.

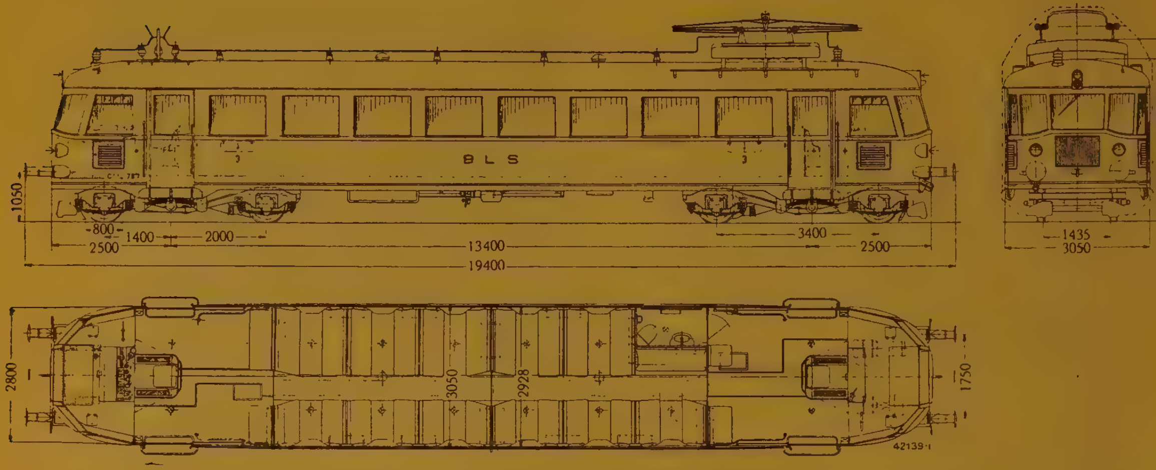


Fig. 153. — Railcar No. 787, type $Ce^2/_4$, BLS, radial axles in bogie frames.

Fig. 154. — Diesel-electric railcar set, 4 units, of the Reichsbahn, 1937, for 160 km./h. (100 m.p.h.), 1937.

The four-coach sets (fig. 154) had an hourly rating of 1 200 H.P. and a maximum operating speed of 160 km./h. (100 m.p.h.), the three-coach sets 680 H.P. and 130 km./h. (81 m.p.h.), DC motors and stub hollow shaft (right side of fig. 146) were provided. The Diesel motor of 1 300 H.P. and a continuous output of 700 r.p.m. was mounted in the shorter leading car, together with a generator and auxiliary 150 H.P. unit.

(To be continued.)

[621 .132 .3 (.44)]

New S.N.C.F. three-cylinder compound 4-8-4 locomotive,

by HENRY MARTIN,

Ingénieur des Arts et Manufactures.

(*Le Génie Civil, of the 1st May, 1947*).

The S.N.C.F. have recently put into service a 4-8-4 three-cylinder compound locomotive, which will largely replace the « *Mountain* » locomotives used on the old P.L.M. and Est Railways.

This powerful locomotive is the result of the complete re-building of a 4-8-4 three-cylinder locomotive No. 241.101, which was constructed in 1932 to haul Transatlantic 600 tonnes trains on the Etat Railway, and which were fitted with the Renaud system of valve gear. This engine was described in the *Génie Civil* when placed in service in 1933 (see *Génie Civil* of the 4th March 1933). In 1935, it was exhibited in the French section of the Brussels Exhibition.

The re-designing was carried out by Mr. CHAPELON, who also was responsible for the modification of the Old Orleans Company's *Pacific* locomotives, of which general particulars were given in 1935 (see *Génie Civil* of 2nd March 1935). We would recall that the principal result was to raise the power from 2 000 to 3 700 H.P., which was principally due to the improvement of the low pressure cylinders. A better combustion was obtained by adopting the Kylchap double exhaust system. The rate of combustion was thus carried from 400 to 600 kgr. per m² (81.926 to 122.889 lbs. per sq. ft.), and the production of steam by the boiler increased by approximately 45 %.

Fig. 1. — S.N.C.F. 4-8-4 three-cylinder compound locomotive in working order.

The improvement of the steam distribution also contributed to a large extent to the increase of power.

For the « *Mountain* » locomotive of the Etat system, which required heavy repairs owing to damage to cylinders, and on which the valve-gear had not given satisfaction, Mr. CHAPELON proposed to re-design the locomotive to a compound type, but to keep the 3-cylinder arrangement. The work of the re-building was given to the « Compagnie des Forges et Aciéries de la Marine et d'Homécourt de Saint-Chamond », working as chief contractors.

The boiler modifications were carried out by the « Ateliers de Sotteville », whilst new cylinders were cast by the Saint-Pierre-de-Corps Foundries.

The frame was retained, but reinforced considerably to allow the power which it was expected the rebuilt engine would attain to be developed without trouble.

The hind bissel truck, which was already loaded to the limit, was replaced by a four-wheeled bissel. The front bogie was also modified. Regarding the exhaust, this was replaced by Kylchap triple exhaust, this being the first time this arrangement was used on an engine.

The rebuilt locomotive was finally put into service in April 1946.

GENERAL DETAILS.

The 4-8-4 locomotive (figs. 1-3) has four driving axles weighing 21 tonnes and wheels of 1.95 metres $(6'4\,^{6}/_{8}'')$. The front bogie axles each weigh 17.4 tonnes. The front axle of the rear bissel truck and its rear axle weigh respectively 14.2 and 15 tonnes. The total weight of the locomotive is, therefore, 148 tonnes and its total length 17.765 metres $(58'3\,^{37}/_{64}'')$.

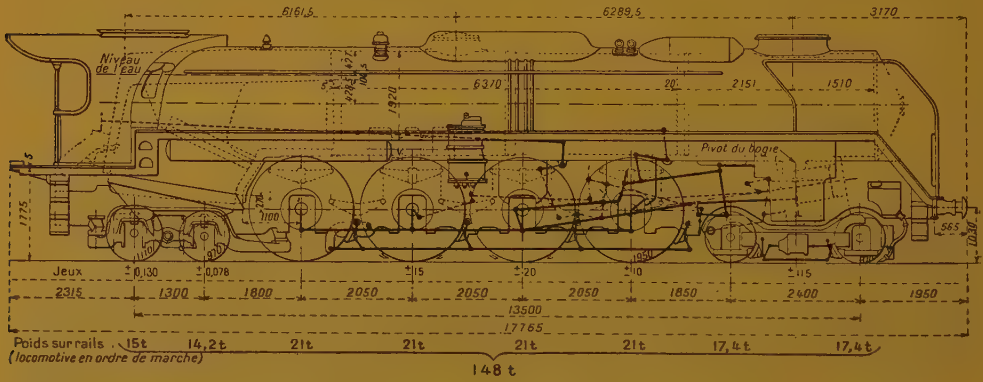


Fig. 2. — 4-8-4 three-cylinder compound locomotive, fitted with superheater and mechanical stoker.

Frame. — The frame is of standard type, the steel plates being 30 mm. $(1\,^{3}/_{16}'')$ thick, reinforced by means of stretchers welded together. This arrangement has been completed by a horizontal sheet joining the two solebars on their upper side and thus forming a very rigid frame. This reinforcement of the frame, taken in addition to other modifications, increased the weight of the locomotive by 20 tonnes.

The adhesive weight has been increased by 4 tonnes, equally distributed on each driving axle.

Another important improvement was the fitting of wedges at the driving axles to automatically take up the play and these were fitted with oilboxes.

To avoid excessive sideplay on the crank axle of the rigid wheel base, the bogie had to be capable itself of ensuring the guiding of the locomotive. It

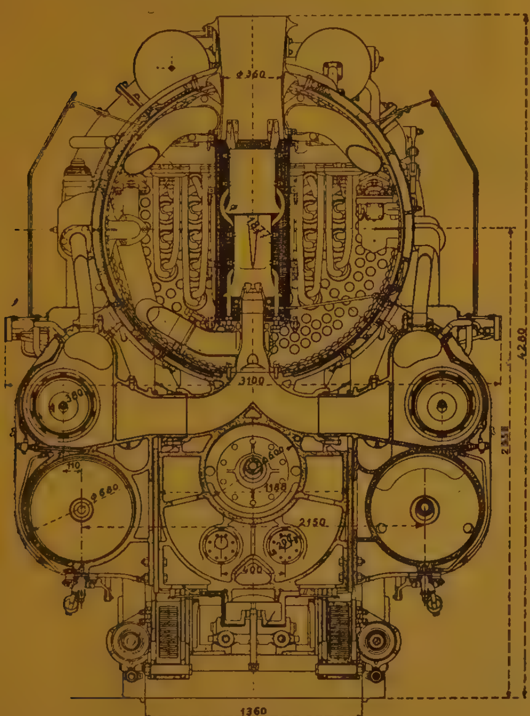


Fig. 3. — Cross-section end view.

had, therefore, to be heavily loaded and fitted with centralising arrangement. This condition was fulfilled by adopting a centralising arrangement fitted with roller bearings worked by gravity.

When working on the main routes, the centralising force is 10 tonnes. When the engine works on routes having curves of small radius, this falls to 6.75 tonnes. This result has been obtained by adopting inclined surfaces on which the roller bearings of the centralising arrangement run. The locomotive can thus easily work round the small radius curves of depots.

Trials, which were carried out, have confirmed the good riding qualities of the engine when working normally. In spite of its length, it works round curves without difficulty. It should be noted that the axleboxes of the front bogie are fitted with Timken roller bearings, whilst similar bogies on the rear bissel are fitted with S.K.F. type.

The rear bissel, which is of American *Delta* type, has a wheelbase of 1.30 m. ($4'3^{3}/_{16}''$). The point where it joins the underframe is 1.80 m. ($5'10^{7}/_{8}''$) in front of its first axle. The *Delta* system incorporates a centralising arrangement by means of American type swing links.

Boiler. — The boiler pressure has been retained at 20 atms. The copper firebox was replaced by a steel firebox fitted with two Nicholson syphons to improve the circulation of water in the boiler. The efficiency of this syphon is shown most clearly during low combustion periods when lighting up, when the regulator is closed and when the engine is hard pressed. The improved circulation of water in the boiler brings about a better distribution of the heating surfaces in contact with the water. The boiler barrel plates are of nickel steel.

The boiler has 127 small tubes, 51.5-57 mm. (2.027-2.244 in.), and 33 large tubes 135-143 mm. (5.314-5.630 in.), of the same length; the distance between tube plates being 6.370 m. ($20'10^{13}/_{16}''$).

The old superheater has been replaced by a Houlet superheater which can attain 420°.

The boiler is fed from the right side by two non-suction type injectors, and on the left side by an ACFI type feed-water heater with pump.

The two safety valves have a diameter of 101 mm. ($3^{62}/_{64}''$).

Exhaust. — The old type exhaust has been replaced by the Kylchap triple exhaust, which, as has already been mentioned, increases combustion (fig. 4).

Stoker. — The locomotives of the Etat Railway were already fitted with an automatic stoker of B type, originating from America. When it was constructed, it was estimated that loading by means of a shovel would be too onerous on the 370 km. (230 miles) of the track from Paris to Cherbourg, for which service the locomotive was designed.

During the rebuilding of the locomotive, this stoker was replaced by a H.T. type, built by the « Société Stein et Roubaix », which type has already been used on certain new locomotives of the S.N.C.F. This latter stoker (see fig. 6) has not the disadvantage found with the previous stoker, of reducing the surface of the grate by approximately 0.60 sq. m. (6.67 sq. ft.).

Fig. 4. — « Kylchap » triple exhaust.

Fig. 5. — Crank axle at leading wheel showing balanced crank webs.

Motion. — The driving axle (fig. 5) is of the *built-up* type of crank with balanced webs for rotating weight only, and not for reciprocating weight. It is made up of 5 pieces of cannon steel, supplied by the Commentry-Fourchambault Company, having an elastic limit of 60 kgr. per mm² (38.09 tons per sq. in.).

The fitting of one crank only allows the crank webs and journals of this axle to have the necessary width and length in relation to the power of such a locomotive. This result could not have been obtained if it had been necessary to place 2 cylinders, even of high pressure, in the space available between the frames.

The inclination of the axis is 15 % for the inside high pressure cylinder, but only 4.4 % for the low pressure cylinders, which are outside.

The high pressure cylinder has an inside diameter of 600 mm. ($1'11^5/_8''$) and a piston stroke of 720 mm. ($2'4^3/_8''$). For the low pressure cylinders the diameter of the piston stroke are 680 and 760 mm. ($2'2\frac{3}{4}''$ and $2'5^7/_8''$) respectively.

The inside high pressure cylinder has

2 piston valves in parallel, of 200 mm. ($7^7/_8''$) dia., which reduces the height required (fig. 3). These piston valves are of the Trick double admission type.

The piston valves of the low pressure cylinders have a diameter of 380 mm. ($1'2^{15}/_{16}''$). They are of the Willoteaux double admission and double exhaust type.

SUBSIDIARY DETAILS.

Starting arrangement. — Starting is carried out at low pressure, due to the fitting of a special regulator mounted on the superheater header and in series with the high pressure regulator. This special regulator permits the direct introduction of steam to the intermediate reservoir at starting.

Fig. 6. — Front view of tender showing the screw conveyer for the stoker.

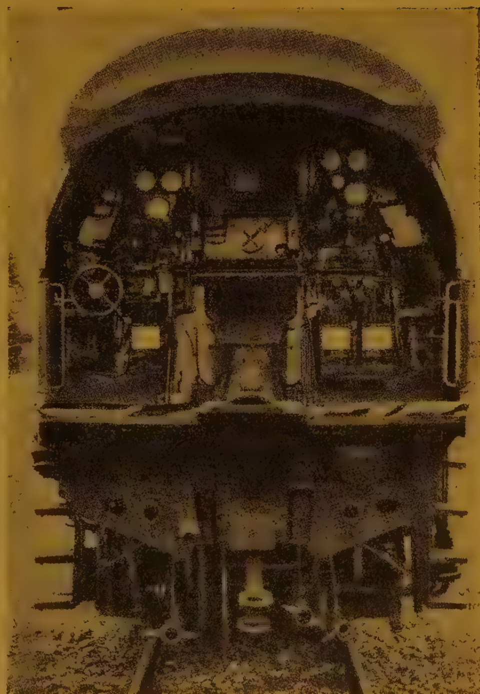


Fig. 7. — Inside of cab.

In addition, an automatic starting valve allows the high pressure regulator only to admit steam to the intermediate reservoir at a pressure varying between approximately ⅓ and ¼ of that admitted to the high pressure cylinder, in order to facilitate shunting in depots.

This arrangement allows the necessary force to be obtained without changing the valves for starting to simple expansion, the pressure of the intermediate reservoir having a maximum of 14 atms.

Lubrication. — The lubrication of the cylinders is carried out by means of a Bosch mechanical lubricator with 20 feeds. The motion is also fed by two Bosch mechanical lubricators, having 20 feeds. All the lubricators are placed

in the cab. There is also a special mechanical lubricator for the compressed air arrangement.

Lighting. — The engine has electric lighting, the current being supplied by a turbo-generator.

Sanding. — The sanding gear is of the compressed air type with sand boxes in front of the bogie and in front of the second and third driving axles.

The main driving axle is not fitted with sanding gear, so that when slipping occurs, the driving wheel is not suddenly stopped.

RESULTS OBTAINED DURING THE FIRST TRIALS.

Trials carried out with ordinary trains were commenced in 1946, and have confirmed all expectations, especially on particularly difficult routes such as Lyons to Saint-Germain-des-Fossés by Saint-Etienne, which has gradients of 6-18 mm./m., as well as on the Paris-Dijon route of which the Laumes to Blaisy-Bas section is one of the most severe on the system.

The results obtained are given below, the force being measured at the tender drawbar by means of a dynamometer car run on level track and at uniform speed :

Bordeaux-Geneva train, 18-7-1946 : Saint-Germain-des-Fossés to Lyons, 15 coaches, 621 tonnes — Time gained : 34 mins., 35 secs.

Gradient of 8.6 °/₀₀; 3 649 H.P. at 92.4 km./hour (57.4 m.p.h.) on 5 km. (3.106 miles); superheat 409°.

Gradient of 11.21 °/₀₀, 3 420 H.P. at 84 km./hour (52.195 m.p.h.) on 7 km. (4.349 miles); superheat 402°.

Maximum power : 4 200 H.P. at 90 km./hour (55.923 m.p.h.) on a gradient of 11 mm./m.

Train 1042, 19-7-1946 : Lyons-Saint-Germain-des-Fossés. — Maximum power : 4 081 H.P. at 72 km./hour (44.738 m.p.h.) on a gradient of 13.75 mm./m.

Train 4, 21-7-1946 : Lyons-Paris. — 13 coaches, 635 tonnes, from Lyons to Dijon; 14 coaches, 693 tonnes, from Dijon to Laroche; 13 coaches, 640 tonnes, from Laroche to Paris. Time gained : 1 hr. 21 mins. in addition to checks.

Gradient 8 °/₀₀; 3 672 H.P. at 96.2 km./hour (59.775 m.p.h.); superheat : 400°.

Maximum power : 3 931 H.P. at 99 km./hour (61.515 m.p.h.).

Run on a gradient Dijon-Blaisy, covered in 19 mins. 45 seconds. Dijon to the entrance of tunnel in 16 mins. 55 secs., speed at entrance to tunnel (gradient of 8 °/₀₀) reached 100 km./hour (62 m.p.h.) (whilst running, high pressure cylinder 70; low pressure cylinder 48).

Train 51, 24-7-1946 : Paris-Dijon, 16 coaches, 701 tonnes.

115 km./hour (71.457 m.p.h.) to Villeneuve-Saint-Georges; 114 km./hour (70.836 m.p.h.) to Combs-la-Ville; 3 220 H.P., 115 km./hour on 9 km. (5.59 miles). Thénissey passed at 114 km./hour after a stop at Laumes; Baisy-Bas passed at 109 km./hour (67.729 m.p.h.); 4 093 H.P. from Verrey to Blaisy.

Train 51, 30-7-1946 : Paris-Dijon, 19 coaches, 831 tonnes.

Maison-Alfort passed at 98 km./hour (60.894 m.p.h.) in 6 mins. 45 secs., kilometric point 12 at 112 km./hour (69.593 m.p.h.).

Speed performances. — From Montrond to Lyons a speed of 100 km./h. was attained at the end of 3 km. (1.864 mile) in 3 mins. 10 secs. Weight of the train : 613 tonnes.

With a gradient of 14 °/₀₀ (run Rives-de-Gier-Saint-Chamond), 9.5 km. run in 9 mins. 50 secs.; the speed attained was 66 km./h. (41 m.p.h.); the drawbar pull on level tracks reached 3 255 H.P. (train 1042 of 19-7-1946); load 596 tonnes.

Shown hereafter are consumption figures which were obtained on the particularly difficult line in both directions from Lyons to Saint-Germain-des-Fossés, *via* Saint-Etienne.

	Load hauled.	Average speed with regulator opened.	Consumption of fuel, inc. lighting up.		
			Total.	Per km.	Per 100 tonnes per km. : BR.
Locomotive 2-8-2.					
Saint-Germain-des-Fossés to Lyons; 11-6-1942; (12 coaches)	518 t. *(509.8 Engl. t.)*	65 km./h. *(40.38 m.p.h.)*	5 760 kgr. *(12 700 lbs.)*	27.8 kgr. *(61.2 lbs.)*	5.35 kgr. *(11.7 lbs.)*
Lyons to Saint-Germain-des-Fossés; 8-7-1942; (13 coaches)	549 t. *(540.3 Engl. t.)*	66.8 km./h. *(41.5 m.p.h.)*	6 319 kgr. *(13 930 lbs.)*	30.9 kgr. *(68.1 lbs.)*	5.63 kgr. *(12 lbs.)*
Saint-Germain-des-Fossés to Lyons; 9-7-1942; (12 coaches)	518 t. *(509.8 Engl. t.)*	66.5 km./h. *(41.32 m.p.h.)*	5 078 kgr. *(11 200 lbs.)*	24.78 kgr. *(54.6 lbs.)*	4.76 kgr. *(10.4 lbs.)*
Locomotive 4-8-4.					
Saint-Germain-des-Fossés to Lyons; 19-6-1946; (14 coaches)	563 t. *(554.1 Engl. t.)*	69.95 km./h. *(43.46 m.p.h.)*	5 080 kgr. *(11 195 lbs.)*	24.58 kgr. *(54.1 lbs.)*	4.36 kgr. *(9.6 lbs.)*
Lyons to Saint-Germain-des-Fossés; 18-6-1946; (13 coaches)	570 t. *(560.9 Engl. t.)*	62.95 km./h. *(39.11 m.p.h.)*	5 478 kgr. *(12 077 lbs.)*	26.7 kgr. *(58.8 lbs.)*	4.60 kgr. *(11.1 lbs.)*
Saint-Germain-des-Fossés to Lyons; 20-7-1946; (15 coaches)	613 t. *(603.3 Engl. t.)*	61.80 km./h. *(38.39 m.p.h.)*	5 252 kgr. *(11 578 lbs.)*	25.42 kgr. *(56 lbs.)*	4.15 kgr. *(9.14 lbs.)*

These trials were carried out under comparable conditions with :

1) 2-8-2 compound locomotive having four cylinders, boiler pressure 20 atms. and 400° of superheat with stoker. This is one of the most economical engines recently placed in service.

2) 4-8-4 locomotive, which we have just described.

These results show that, from the point of view of fuel consumption, the compound 3-cylinder locomotive is better than the compound 4-cylinder locomotive.

The S.N.C.F. have, therefore, a prototype locomotive, which is better than the most powerful modern engines placed in service up to the present time.

[621 .133 .3 (.73)]

Design and construction of staybolted fireboxes,(*)

by F. P. HUSTON†.

(From Railway Mechanical Engineer, April 1948.)

This paper will discuss features of design, choice of materials, and methods of staybolt application. In dealing with the elements of design, material and construction, it is hoped that new possibilities may be seen for the application of the staybolted firebox. It will be apparent that staybolt leakage is very much a part of the problem of design and the choice of materials. All recommendations and suggested changes are predicated upon the assumption that effective means will be taken to avoid staybolt leakage. These means will be discussed more fully in a latter part of this paper.

Design features.

The use of two simple rules appears to be the guiding principle in our present-day designing practice. The first tells the designer what maximum spacing is permitted to be used for a given sheet thickness and working pressure. The second rule states that the maximum stress which can be applied to the staybolt due to boiler pressure is 7 500 lb. per sq. in. Both of these rules are taken from the work of the noted British engineer, William Cawthorne UNWIN who was born in 1838 and died in 1933 at the age of 95.

Considering the fact that the formula from which the present code formula is derived was considered, years ago, to be unsatisfactory and that consideration has not been given to the proven ability of the present-day firebox sheet material, particularly the alloy steels, to safely withstand stresses considerably greater than 7 100 lb. per sq. in. under comparable conditions of service, it would seem useful to initiate a research program to establish stress allowances more in keeping with modern design practice and materials. The 7 500 lb. per sq. in. stress limitation on staybolts is even more restrictive than the limitations placed on the sheets. As in the case of firebox sheets, this stress limitation on staybolts is apparently taken from Unwin, who limits the working stress to a maximum of 5 000 lb. per sq. in. for copper stays, 7 500 for iron and 9 000 for steel.

Actually, the 7 500 lb. per sq. in. limitation requires the use of staybolts of such size as to impose higher stress on the structure, particularly on the fire sheet and staybolt fastening than would be obtained with smaller diameter staybolts stressed to some higher value. This is true because stresses due to bending are superimposed on the static tensile stress due to boiler pressure. For example, suppose that one-inch diameter straight body staybolts spaced on 4-in. by 4-in. centers are stressed to 7 000 lb. per sq. in., which is obtained at 271 lb. per sq. in. boiler pressure, were replaced with $^7/_8$-in. straight body

(*) Abstract of paper presented before the Railroad and Metals Engineering divisions, American Society of Mechanical Engineers, on December 2, 1947, at the annual meeting of the society at Atlantic City, N.J.

† Deceased. Mr. Huston was formerly in charge of railroad development, Development and Research, International Nickel Company, New York.

staybolts, then the direct tensile stress is increased to about 9 260 lb. per sq. in. However, for a given degree of bending, due to displacement of the fire sheet in respect to the wrapper sheet from temperature differences, the total stress, which is the direct tensile stress plus the tensile bending stress, is actually lower. It is the total stress that causes staybolts to leak, resulting in cracked sheets, or to break.

Specifically, for a total displacement of 0.020 in. between sheets spaced 8 in. apart, the bending stress on the one-inch staybolt is calculated to be 24 400 lb. per sq. in. and on the $^7/_8$-in. staybolt, 20 900 lb. per sq. in., making the total stress in tension 31 400 lb. per sq. in. and 30 600 lb. per sq. in. respectively. The resistance to bending which is translated into tensile and buckling stresses in the thinner firebox sheet, is reduced from about 870 lb. per stay for the one-in. diameter staybolt to about 460 lb. for the $^7/_8$-in., or a reduction of 46 per cent.

The high costs incurred through the use of oversize staybolts is well demonstrated in tests which showed a decrease of 39 per cent in the average mileage life of side sheets when $1^1/_{16}$-in. diameter stays follow an application of 1-in. diameter. In addition, about 14 per cent more dead weight is added to the weight of staybolts on the trailing trucks with a comparable increase in the cost of material. The use of $1^1/_8$-in. diameter stays which average one-third less mileage life with nearly one-third more dead weight and nearly one-third more material costs over one-inch diameter, is equally striking. It is significant that $^7/_8$-in. diameter straight body staybolts meet the 7 500 lb. per sq. in. limit for 20 lb. per sq. in. boiler pressure with a 4-in. spacing and could be expected to effect an appreciable increase in side sheet life over the one-inch diameter stays with lower weights and material costs.

The advantage of smaller diameter staybolts with correspondingly closer spacing as compared with current staybolting practices is indicated in Fig. 1, which shows the stress-deflection relations of three assemblies tested at the Massachusetts Institute of Technology These are the stresses in the plate at an

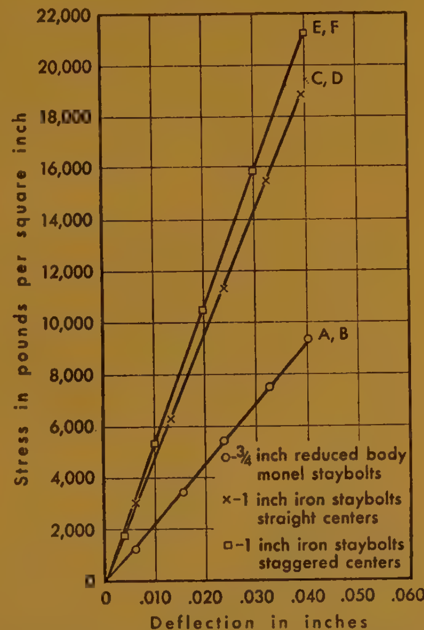


Fig. 1. — Stress-deflection relationships of three assemblies. — The one-inch staybolts are spaced on 4-in. centers; the ¾-in. reduced-body staybolts are on 3½-in. centers.

average distance of about $^3/_{32}$ in. from the edge of the hole. The concentrated stress at the edge of the hole where cracking starts may be two or more times these measured stresses. The measured stresses of 19 300 lbs. per sq. in. and 21 300 lbs. per sq. in. at 0.40-in. deflection for the assemblies stayed with one-inch iron staybolts may be increased to stresses of the order of 38 000 to 42 000 or higher as concentrated stresses at the edge of the hole. These are re-

duced to less than half by the change to the smaller staybolt in assembly No. 3.

It is obvious from these tests and from observations in service that, since locomotive fireboxes continue to give service sometimes over long periods of time, our conception of design in respect to the properties of material must be revised to allow for a certain amount of over-stressing as a normal operation condition. It is through changes in the safety rules that the degree of over-stress can be held within more reasonable bounds, perhaps avoided, to enable the material to work at stress levels below the proportional limit.

The type of staybolt is definitely an element of design becoming increasingly more important as the length of the staybolt decreases in the narrow water spaces. The choice lies between the straight-body type for the narrow water space and the reduced-body type. The longer stays, of about 10 in. length and longer, have, for obvious reasons, the reduced-body section, usually made up by upsetting the ends. The reduced-body staybolts offer advantages over the straight-body type, particularly in the shorter lengths as used in the narrow water spaces. These include : (1) Improved stress distribution between the staybolt, the sheets and the fastenings; (2) Greater freedom in design to control distortion and stress relations between adjacent areas of the structure; (3) Reduced dead weight; (4) Economy of material, and (5) Two or three times more bolts can be threaded and run in per hour.

Now that staybolt leakage is recognized as the prime cause of firebox sheet failures, a new concept of the properties of sheet materials provides a more reliable guide in selecting sheet materials for long service life than was had heretofore.

A great deal of effort has been expanded to develop a firebox steel that will resist failures due principally to cracking. Much of the early work was done by the Germans in following the hypothesis that ageing characteristics exerted an important influence on cracking, and as a result the heavily aluminium deoxidized steel known as « Izett » was placed on the market, which, in laboratory tests, was shown to be virtually non-ageing. Much work was done with the nickel steels, and it was proven that nickel strongly inhibits ageing effects. However, in spite of the rather large amount of study that has been directed to steels of special composition and manufacture, no significant progress was made in eliminating the cracking of firebox sheets because in these studies the influence of leakage was considered to be unimportant.

Comparative tests of three different steels were made on an eastern railroad in three classes of locomotives involving a total of 17 locomotives. One of these steels was the railroad's specification deoxidized carbon steel which has been standard for a number of years. The other two steels were steels offered by producers as having properties better suited to firebox service than carbon steel. Each locomotive in the test was fitted on one side with one kind of steel and on the opposite side with another kind. In all but two instances, failures occurred in both steels at the same mileage in each locomotive. There is no significance to be attached to the deviation in the two non-conforming cases.

A second eastern railroad duplicated this test, applying their standard specification deoxidated carbon steel on one side in comparative tests with three low alloy firebox steels. At this writing (Aug. 1947), five pairs of sheets have failed, including failures of all three special steels. The average mileage life obtained was 88 000 with a maximum of 107 000 and a minimum of 70 000 miles. Each sheet of the pair failed at the same mileage and location, involving practically the same number of staybolts.

The first railroad has in progress a second series of performance tests. Several pairs of sheets have failed in this second series, also at the same mileage. It seems that the consistency of the results of these controlled series of tests, coupled with scattered data gathered from locomotives on these and other railroads, should prove beyond reasonable doubt that the service life of firebox sheets bears no significant relation to composition, method of manufacture or physical characteristics of the ferritic steels.

Alloyed steels, regardless of the alloys used, or carbon steels of special manufacture, regardless of method, cannot be expected to show any advantages one over the other under the conditions applying. It is significant here to note that the conditions which applied in these tests and in the scattered service data referred to included the use of staybolts applied in the conventional manner of screwing through with ends riveted over. It seemed apparent from early failures in the series of tests, since composition and properties have no appreciable effect on service life, that staybolt leakage resulting in intercrystalline embrittlement is the basic cause of the cracking of firebox sheets.

Staybolt leakage.

On this assumption a series of tests was started to determine to what extent staybolt leakage was the cause of cracking of firebox sheets. The first locomotive in this series of tests was placed in service in June, 1942. The results of these tests, together with those from other railroads, have well proven that staybolt leakage is the immediate cause of the cracking of sheets.

With this knowledge, a different criterion is provided to select materials best suited to locomotive firebox use. Service data show that for most classes of power the standard deoxidized carbon steel in current use will give satisfactory mileage if staybolt leakage is avoided. With heavy duty power, however, low alloy, high strength steels should prove economical in providing many years of maintenance-free firebox service because of their ability to withstand the more severe conditions imposed on the firebox sheets as the result of higher firing rates, greater temperature fluctuations and the like.

The use of nickel as an alloy is particularly beneficial in conferring optimum combination of properties — high strength with improved ductility and toughness at low carbon levels. This nickel steel is covered by Grades « A » and « B » of A.S.T.M. Specification No. A-203. For particularly severe conditions, which may be encountered in special cases where boiler water scale may cause the overheating of firebox sheets the use of nickel-clad steel, applied with the nickel on the water side to prevent scale adherence, is indicated.

Staybolts.

It has been shown (*) that staybolts in locomotive boilers are normally subjected to stresses exceeding the yield point of the material. A study of the division of a firebox into « breaking » and « non-breaking » zones indicates clearly the existence of a « threshold » level of stresses marking a rather sharp demarcation between locations where breakage frequently occurs and locations where breakage seldom occurs. It becomes evident at the division line of the two zones that the stresses imposed on a simple type staybolt are just under the threshold and that in the next row, just four inches away, the stresses are just over the threshold. On this continent the almost exclusive use in the breaking zones of flexible iron or steel staybolts,

(*) « A Study of Firebox Materials and Design », pages 519-524, November, 1943, issue. *Railway Mechanical Engineer.*

which are fitted at the outside end with a ball and socket joint, is generally effective in avoiding breakage. This is because the bending stresses are thusly reduced to below the « threshold » values. However, the method is costly and imposes severe limitation on advancements in design and performance of the staybolted firebox.

With the aim of retaining the simple rigid-type staybolt throughout the entire boiler, a change in the nature of the material used in the breaking zones must be made from wrought iron or low-carbon steel to material capable of withstanding the breaking stresses. This problem received first attention abroad over 50 years ago with the advent of the use of copper staybolts. With the need for obtaining materials of higher strength and better corrosion resistance, applications were made as early as 1910 of the nickel-copper alloy « Monel ». Applications of rigid type Monel staybolts throughout the breaking zones in 4-6-2 locomotives on a Canadian railroad are shown in Figs. 2, 3 and 4. A total of twelve locomotives of this construction are in service, two since the middle of 1944 and ten which were built last year. Ample experience and service data are available from the large number of locomotives abroad stayed throughout the breaking zones with Monel and from a sufficiently large number on this continent to supplement these data.

Fig. 3. — Monel « rigids » in throat sheet outlined in chalk.

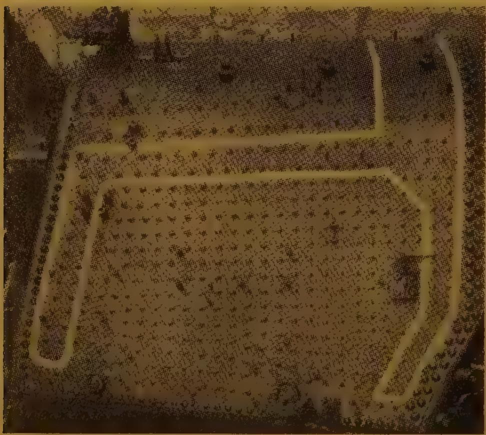


Fig. 2. — All rigid-type staying in Pacific type locomotive side sheets and expansion zone stayed with Monel « rigids » as outlined in chalk.

In the non-breaking zones, where the stresses are below the threshold value for wrought iron and steel, rigid type staybolts may be used with little danger of breakage. Wrought iron is used in fully 80 per cent of the locomotives in this country. Nickel-steel staybolts are used in practically all of the remaining 20 per cent and are standard throughout Canada.

The comparatively recent development of seal welding, and its rapidly increasing use, has given impetus to the adoption of low-carbon alloy steels in place of wrought iron for staybolts. Nickel staybolt steels, containing up to about 2.25 per cent nickel, have been in successful use on this continent and abroad for many years. Other low alloy steels are currently being tested for this service.

Fig. 4. — Monel « rigids » in back head outlined in chalk.

Staybolt leakage.

That leakage of staybolts is the immediate and prime cause of the cracking of firebox sheets is proven beyond reasonable doubt from service records dating back to June, 1942.

Data based on mileage records are reliable in establishing the fact that staybolt leakage is the important cause of cracked sheets and that by advoiding leakage the cracking of side sheets is apparently cured. The results are even more striking where leak-tight application is made in one side and the conventional, or leaky, method is used in the opposite side of the same locomotive. A number of such tests have been in progress for the past several years. A good example is shown in Fig. 5, where the evidence of leakage in the riveted-over side is unmistakable. This type of application was made in two Hudson-type locomotives which were placed in service in June and July, 1945. The leaky sheets of both required extensive patching in July of this year (1947). The seal welded sides do not show any ill effects.

Today, seal welding has been applied in about 300 locomotives in this country and Canada. Several roads have established seal welding as standard practice, and the problem of cracked firebox sheets, which has been so costly in the past, can now be considered satisfactorily solved in view of the performance records. Leak-tight construction has done more than reduce the cost of firebox maintenance — it has opened the way for advances in the design and construction of the staybolted structure which have been so long retarded. Obvious improvements can now be made with reasonable assurance that the benefits can be realized where, heretofore, premature failures because of leakage obscured the effects of the change.

Several procedures are in use for seal welding involving variations in the preparation of the end of the staybolt from a square end to several degrees and shapes of chamfers in the length extend-

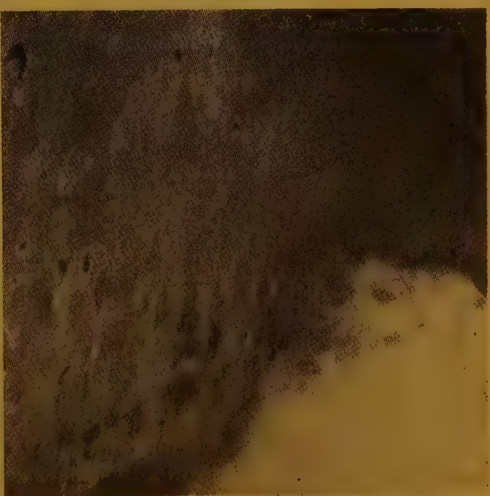


Fig. 5. — Leaky riveted-over staybolts in left side of firebox in test of riveted-over vs. seal welding.

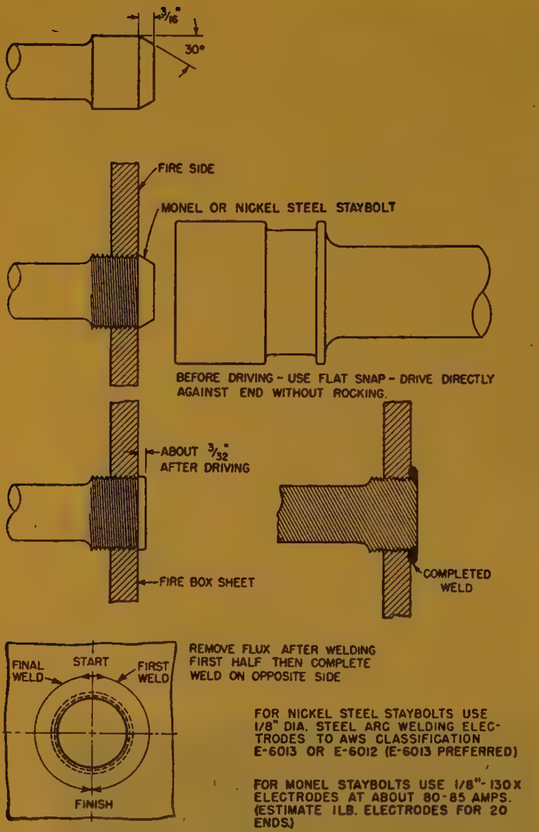


Fig. 6. — Recommended procedure for seal welding staybolts on the fire side.

ing beyond the fire sheet, in holding on, hucking-up and driving, and in the position of the start and directions for welding. These differences are probably of little consequence in obtaining a welded steel against leakage. They may, however, be of considerable importance in respect to the possibility of failures from cracked welds with threads that are too loose or too weak to prevent over-stressing the root of the weld when severe displacement of the fire sheet occurs.

Many degrees of thread fit, from very loose to tight, result from the wide variations among roads in tap and staybolt pitch diameter tolerances, and in tapping practices. In making early test installations of seal welding on several roads in this country about five years ago, the relatively loose thread fits encountered made it necessary to hammer the staybolt on the fire side before welding. The recommended procedure shown in Fig. 6 was developed from the experience gained on these roads, and Fig. 7 shows the finished seal welded ends.

Shortly after the early work was done in this country, a Canadian road applied seal welding in one side sheet in each of two locomotives for comparison with conventional riveted-over construction in the opposite sides. It was found that the practice on this road gave thread fits sufficiently tight to make hammering or driving on the fire side unnecessary. The staybolt is « bucked-up » with a dolly on the fire side for hammering and riveting-over the outside end, and then seal welding is applied without further hammering. The soundness of this procedure is evidenced by the complete freedom from leakage in the seal welded sides in these two locomotives, as well as

Fig. 7. — Seal welded staybolts.

in more than fifty locomotives placed in service after this seal welding procedure had been adopted as the standard.

As an approach to eliminating hammering on the fire side, one of the leading staybolt tap manufacturers is producing a standard tap well suited to obtaining the degree of tightness required. The length of threads on the tap is sufficient to maintain continuity of lead for water spaces of 11 in. and under. The thread is commercially ground to basic pitch diameters plus and minus 0.0005 in. With these taps, good fits have been obtained in several recent applications with staybolts threaded 0.002 in. over basic pitch diameter. The proper size for the degree of fit required must be determined by trial until such a time as suitable accurate standards are developed. For fits sufficiently tight to make hammering unnecessary, a degree of fit appproaching the Class 5 interfering fit is required.

Stripping of the threads is avoided through the use of graphite in the oil used for tapping or applied to the staybolt for running in. Collodial graphite is highly efficient and used in the proportion of 2 oz. of a 20 per cent suspension to form a quart to a gallon of oil. Suitable oils for tapping include red engine oil, castor oil and water soluble oil. The use of graphite on the threads of all staybolts is advisable against stripping, particularly where thread lead is not maintained.

Explosively-set staybolts.

Early in the studies leading to a workable solution of firebox failures, it was realized that to obtain the maximum efficiency against leakage in the screwed staybolt fastening a means was required to effectively expand the staybolt into the sheet to obtain a strong metal-to-metal fitting over all engaging threads. The Henschel method of expanding by drifting had been in use over twenty-five years abroad for both steel and Monel staybolts with good success but only a passing interest was shown here in the method because of its higher cost and the need for staybolts and tools of special design.

The idea of effecting the expansion with an explosive was presented to the research staff of the du Pont organization, who started experimental work early in the summer of 1941. Initial trials led to the successfull application of Monel and nickel-steel staybolts on two Canadian roads.

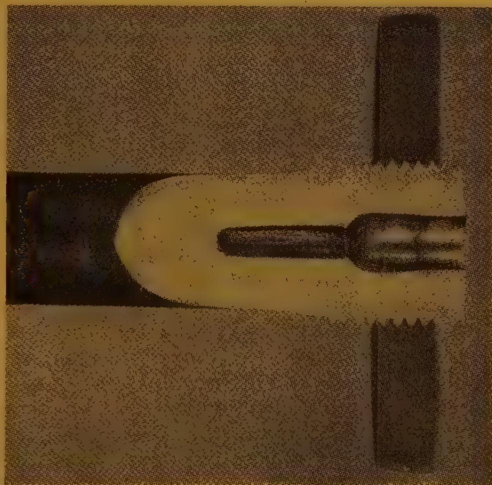


Fig. 8. — Section of staybolt expanded with explosive cap.

Electric firing was used in the installations now in service, but this method has been superseded by a « gun » recently developped by Canadian Industries Limited, which makes it possible to use a cheaper type of blasting cap, eliminates the time-consuming preparation of electrical connections formerly required and greatly reduces the noise from the explosion. With the « gun », caps of the type normally ignited by means of a fuse are fired by directing

the flame from the primer of a .22 calibre cartridge into the end of the cap.

The explosive method virtually eliminates the human equation. With the old method there was no way of determining the condition of the threads after hammering. With the explosive method, the degree of expansion is determined by simply gauging the size of the hole. After firing, the staybolt end may be finished by rolling-over the edge with a smooth bobbing tool. An alternate method, which incorporates the best of our present knowledge in fitting screwed staybolts, consists of seal welding followed by expanding with the explosive cap.

Fusion-welded staybolts.

Eventually, the screwed staybolt will be relegated to the past and the fusion welded fastening substituted.

Tests completed in October, 1946, on welded vs. screwed staybolts (conducted under the direction of a special A.S.M.E. Committee on welded stay construction in power boilers under the chairmanship of W. D. HALSEY) have resulted in the acceptance of the fusion-welded stay in lieu of threading. The fusion-welded staybolt was proposed for locomotive boilers during a meeting of the Master Boiler Makers Association, five or six years ago, and a limited amount of test work has been undertaken by one of the leading roads.

In view of the present status of fusion welding as a reliable method of construction and the inherent strength, ductility, and other desirable properties of the fusion welded joint, it seems reasonable to predict that its adoption as a permissible staybolt fastening in locomotive boilers may be expected.

The formulating of rules for welding staybolts to assure safe practice in all railroad shops were welding is apt to be used can be expected to present difficulties, due to the refusal in some shops by the welders to qualify, seniority rules which can result in unskilled welders doing the work, and other factors. It is unfair to the large number of railroad shops where procedure controls can be applied and good work done to penalize them through rules and regulations aimed at those shops where proper work is not being produced and where controls operative in modern fabricating shops are not now being exercised.

During the time this rather knotty problem is being studied, welding engineers, in cooperation with boiler designers, could well give thought to the requirements to be met in providing a proper fusion-welded stayed structure for locomotive service. The essential difference between stationary and locomotive boiler operation is in the greater severity of stresses imposed on the staybolts and fastenings in locomotive fireboxes, from the rapid temperature changes encountered during cooling-down, boiler washing, firing-up and often misuse of boiler feed pumps and, to a lesser degree, the variations in firing rates. These stresses, often exceeding the yield point of the staybolt material, are bending stresses superimposed upon the static tensile stress due to the boiler pressure. The use of upset ends on the welded stay with a more liberal allowance of the maximum permissible stress due to boiler pressure in the body of the stay can be expected to effect improved stress distribution and to lower maximum stress concentrations.

In view of the paucity of reliable data on the staybolted structure as a whole, the introduction of the fusion-welded stay could well promote an early start on a research project under the sponsorship of the A.S.M.E. The results of the tests should be more readily accepted by the Bureau of Locomotive Inspection and the roads if made in either locomotive boilers, or if need be, in locomotive-type boilers such as used in the oil fields.

Research of this nature is best con-

ducted in a test plant by a railroad testing organization where means are available to closely simulate locomotive boiler handling and operating conditions. These could include dumping of the fire, rapid cooling-down and firing-up, introduction of cold feed water through side boiler checks and other conditions likely to impose the abnormal thermal shocks largely responsible for firebox failures.

Conclusion.

In conclusion, it may be said that the staybolted firebox is well suited to meet the requirements of modern locomotive boilers. The stayed structure is inherently strong, and yet adequate flexibility or, if necessary, controlled rigidity is readily provided by suitably proportioning the pacing, sheet thickness and staybolt diameter.

Modifications could well be made in the present design practices to obtain greater benefits from improved materials and methods of construction. More liberal working stress allowances than are now permitted in code and safety rules seem advisable for the higher working pressures in use today and are obviously necessary if the staybolted firebox is to be used for pressures up to 500 lb. per sq. in. or so desired for steam turbine drives. It can be further stated with confidence that a very considerable improvement in maintenance and repair costs, reliability, safety and weight of the staybolted firebox can be obtained through relatively minor changes in design and the use of modern materials properly applied.

[621 .132 .8 (.73) & 621 .438 (.73)]

Turbine-electric locomotives for the Chesapeake & Ohio Railway.

A 6 000-H.P. turbine running at 6 000 r.p.m., is supplied with steam from a conventional coal-fired boiler.

(From *The Railway Gazette, March 5, 1948.*)

In June, 1947, the first of three 6 000-H.P. turbine-electric steam locomotives for the Chesapeake & Ohio Railway was exhibited at Atlantic City. The design of this locomotive is especially notable, not because of any revolutionary new device, but for the ingenious arrangement of the principal components. The coal bunker is at the leading end, next comes the cab, and then the boiler, followed by the turbo-generator. Water is carried in a separate tender behind the locomotive. The locomotives are being built by the Baldwin Locomotive Works, and have been designed by the technical staffs of the C. & O., the Baldwin Locomotive Works, and the Westinghouse Electric Corporation, working in collaboration.

The first of the three Chesapeake & Ohio Railway steam turbine-electric locomotives.

The new locomotives are intended for high-speed passenger traffic between Washington and Cincinnati, a run which includes long stretches of heavy mountain grades in the eastern portion, and of level-track territory, suitable for high speeds, in the western portion.

Comparison of this design with the geared turbine locomotive (see *The Railway Gazette,* May 31, 1946, issue), built by the Baldwin Locomotive Works, in

conjunction with the Pennsylvania Railroad, shows that each system has its advantages and limitations (Fig. 1). The turbine-electric drive is somewhat heavier, owing to the d.c. generators; however, the turbine always rotates in the same direction, never slower than 60 per cent. of rated speed. This means a much reduced steam demand on starting. The mechanical drive requires a separate small turbine and clutch for reverse operation. In the Pennsylvania

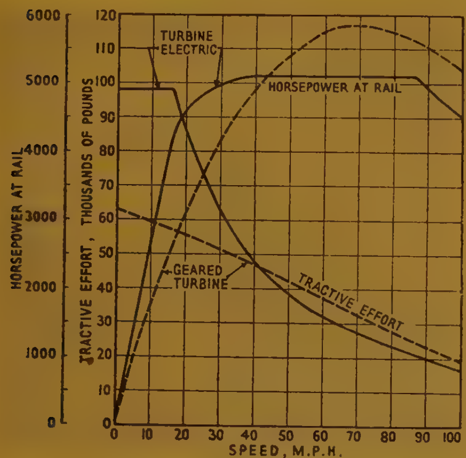


Fig. 1. — Horsepower and tractive effort characteristics of steam-turbine locomotives rated at 6 000 H.P. and using identical boilers.

geared turbine locomotive, all the power is applied to four pairs of driving wheels, whereas the Chesapeake & Ohio turbine-electric locomotives have power on eight axles. Vibration and hammer blow are absent from both types.

The main power unit comprises a turbine, a 6:1 reduction gear, and two double-armature generators. The steam turbine is of the impulse type, having a velocity-compounded impulse-control stage followed by four full-admission impulse stages. Steam flows to the turbine through a seven-valve steamchest cast integral with the turbine-cylinder cover. Each valve is connected by a cored passage to a nozzle group which admits steam to a portion of the control stage. The single-seated diffuser-type valves are connected to a common lift bar. The individual valve stems open in sequence, thus minimising the throttle loss at any opening. The governor-operated hydraulic piston raises and lowers the valve lift bar through a yoke and link. A mechanical strap-type transformer governor, driven from one of the low-speed gear shafts, controls the position of the hydraulic operating piston. The 8-in. throttle valve, located on the side of the steam chest, closes automatically on turbine overspeed.

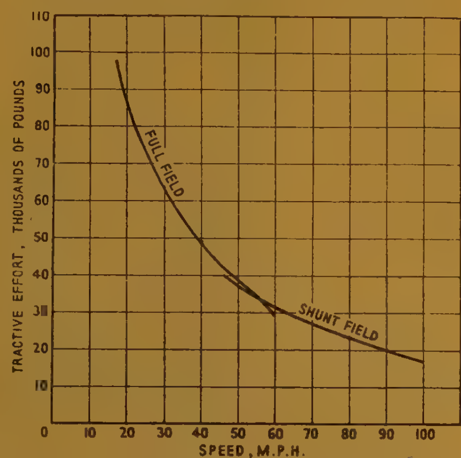


Fig. 2. — Tractive effort and speed curves for different operating conditions as recorded with full throttle on the turbine.

Turbine and gear have whitemetalled sleeve bearings; a segmental type thrust bearing at the exhaust end of the turbine governs the position of the turbine and pinion shaft. Each low-speed gear-wheel journal bearing has a thrust collar which positions the gear and generator shaft.

Built into the gearcase assembly is an

oil reservoir of about 200 gal. capacity. Part of the oil is used to operate the governor; the remainder is reduced in pressure through an orifice and is used to lubricate the journal bearings and gears. The oil system contains a magnetic strainer and a shell and tube type cooler, through which boiler feed water is circulated. Automatic bypass controls regulate the temperature of the oil leaving the cooler.

Generators.

The two generators have their armatures mounted on the gear shaft with the commutators facing outward. The outer end of each generator shaft carries a pulley which drives, through multiple V-belts, an auxiliary generator mounted on top of the main generator.

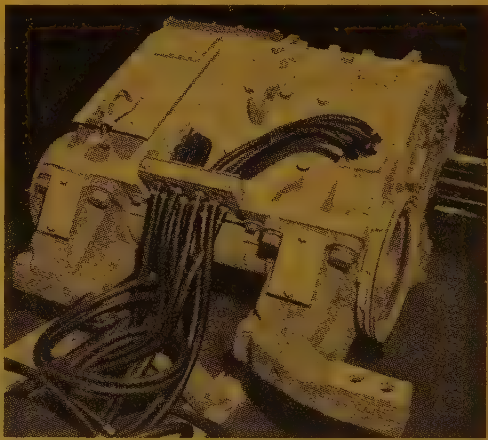
A turbine-driven vertical propeller-type fan, mounted on one side of the main turbine, supplies air to the space between the two stators of each double generator. From this point the air flows in both directions towards the commutators, thus carrying any carbon dust out of the machine. An auxiliary duct carries cold air directly to the generator commutators.

The main generators are eight-pole, multiple-wound, commutating-pole d.c. machines with two windings on the main poles. The main exciting winding is connected to the armature through a regulating resistor. A field discharge resistor is connected through a Rectox unit to prevent excessive voltages when opening the field circuit. The regulating resistor is adjustable in two steps. The first is sufficiently high to prevent uncontrolled build-up; the second permits maximum voltage to be obtained.

A voltage relay connected to the generator armature controls the change-over from one winding to another. The separately-excited field is controllable in eleven steps by the master controller, which obtains its power from the same generators which supply excitation.

Traction motors.

Each of the four generator armatures supplies power to two 620-H.P., 568-volt, 720-r.p.m. traction motors connected in parallel. These are 6-pole series-wound axle-hung d.c. motors geared with single-reduction spur gearing to the driving axles. They are force-ventilated by air from the turbine-driven vertical propeller-type fans through ducts built into the locomotive underframe. On the

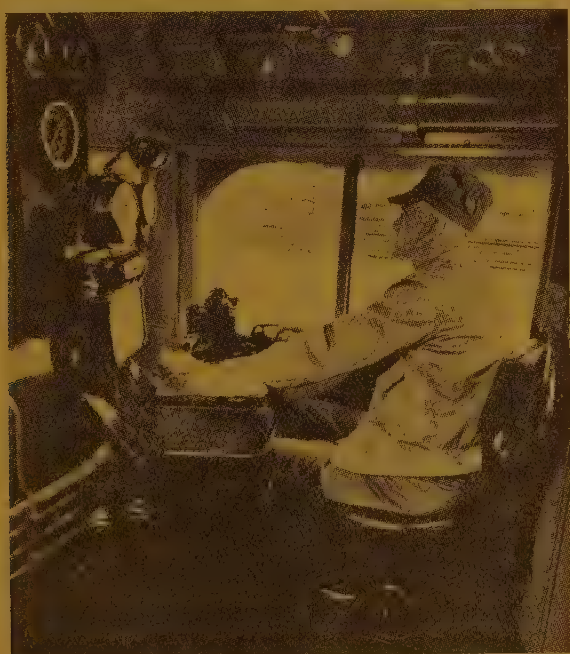


One of the eight 620 H.P. traction motors.

front end the fan is located in front of the coal bunker, and supplies air for the three traction motors mounted on the front bogie. The fan for the five motors on the rear bogie is mounted on the opposite side of the main turbine from the generator blower. All these fans have centrifugal type air cleaners which remove much of the dirt and cinders drawn in with the ventilating air.

Because this is a coal-burning locomotive, it was desirable to take special measures to provide the electrical equipment with air free from smoke and steam. All air for the blowers, therefore, is taken into the locomotive ahead of the chimney. A bulkhead separates

the blowers in the rear compartment, so recirculation of air is negligible. The electrical control equipment is separated by removable doors from the heated air discharged from the generators. This compartment is ventilated with outside air in summer, and with heated air in winter to prevent condensation. Since ed by varying the strength of the separately-excited fields of the main generators, and part by speed control of the turbine. To obtain a satisfactory water rate, the speed of the turbine is not reduced below 60 per cent. of the full speed in the idling position of the controller.



Driver's position in cab. The coal space is ahead and the boiler is behind the driver.

the ducts discharging the dirty air from the cleaners to the outside could not be made as short and straight as was desirable, a high-pressure airscavenging system is provided for occasional operation on each run.

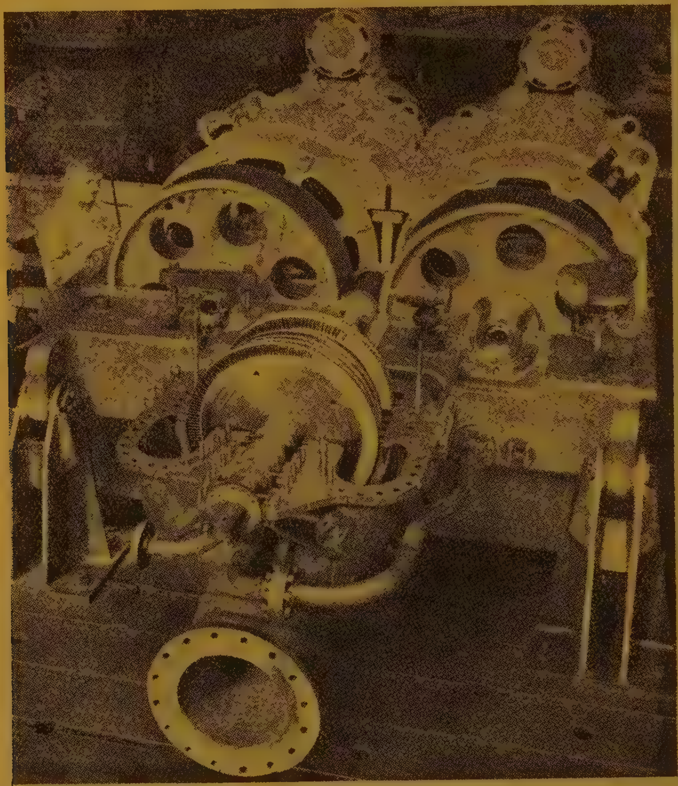
Electrical control.

The electrical control differs from that used on diesel-electric locomotives in that part of the acceleration is obtain-

The control equipment for the main generators and the motors mounted on the rear bogie is in a compartment behind the generators. The control equipment for the motors on the front bogie is under the coal bunker.

The master controller, located at the engineman's position, has two handles, controlling speed and direction respectively. When the speed handle is moved from « off » to « idle », steam is admitted

to the turbine, bringing it to the idling speed — about 3 600 r.p.m. This is the condition obtaining when the locomotive is stopped for short periods, as at stations. Moving the controller to the first speed position applies excitation to The self-excited field is also connected to position 1, but has little effect until the generator voltage increases. Further movement of the master controller increases the turbine speed to the full amount.



Power plant, viewed from above, with upper turbine and gear casings removed.

the generator fields and power to the traction motors, while movement successively through the additional positions increases the power step by step to the point at which maximum separate excitation has been applied to the generators, and the turbine speed is increased to 75 per cent. of full speed.

A meter panel at the engineman's position indicates traction motor current and turbine speed. These meters are lighted at night with ultra-violet light which eliminates all glare and affords maximum eye comfort for the engineman. A buzzer is provided to indicate wheel slipping; and there are lights to

indicate tripping of overload relays, operation of earthing detector, functioning of blowers, and temperature and pressure of lubricating oil.

The traction motors are connected to the generators by electro-pneumatic switches. The fields of the traction motors are connected to a drum type reverser which in turn is controlled by the reverse camshaft of the master controller.

One step of field shunting (Fig. 2) is provided by a non-inductive resistance connected across the motor fields by an electro-pneumatic switch. This switch is controlled by a voltage relay connected across the generator armature.

The slip relays are connected between the two traction motors supplied by one generator, the connection being made between the armature and the field in each case. As long as the back E.M.F., and consequently the speeds of the two motors, are equal, no current passes through the relay. As soon as a wheel slips, the back E.M.F. of its motor increases, which closes the relay contacts, thus operating the warning buzzer. It does not shut off or reduce power.

Overload relays in each motor circuit are set to trip at the maximum accelerating tractive effort. If any of these overload relays operate, the emergency trip magnet valve is de-energised and the governor closes immediately, thus relieving the overload. Before load can be re-established, the master controller must be moved to the « off » position.

The master controller contacts are connected to a panel having the twelve contactors mounted on the front, and the regulating resistors mounted on the rear.

Any generator armature and its associated traction motors can be disconnected should trouble occur in any of them. In that case, three-quarters of capacity is available. Copper strap, insulated with mica and glass, has been used for the main power-circuit wiring; cable is used only where flexibility demands it.

Two 9-kW. 75-volt generators supply auxiliary power, although either one alone has sufficient capacity to supply the maximum load. This results in increased reliability. A single regulator controls both generators, and they are paralleled through a balancing resistor. Either may be idle without in any way affecting the operation of the locomotive.

These auxiliary generators also supply power to the air brake system and to the mechanical lubricator pump. This pump is controlled also by the master controller, and is stopped when the locomotive is at rest, thus preventing waste of lubricating oil.

Having regard to the size of the locomotive, the control equipment is simple, while it also permits operation at any position of the controller for any desired length of time.

Principal design data.

Tractive force (continuous)	48 000 lb.
Speed at continuous tractive force . .	40 m.p.h.
Maximum starting tractive force (limited by traction motors)	98 000 lb.
Maximum speed (limited by traction motors)	100 m.p.h.
Driving wheels, dia. .	3 ft. 4 in.
Total engine wheelbase	90 ft. 7 in.
Total engine and tender wheelbase . .	130 ft. 7 in.
Turbine output at 290 lb. per sq. in. gauge, 750° F., and 15 lb. per sq. in. back pressure . .	6 000 H.P.
Turbine speed . . .	6 000 r.p.m.
Weight of electrical equipment	151 845 lb. (67.4 tons)

Weight of turbine-generator unit . . 83 000 lb. (38.0 tons)

Weight of traction motor . . . . . . 7 380 lb. (3.3 tons)

Weight of engine in working order . . 750 000 lb. (324.7 tons)

Weight of engine and tender in working order . . . . 1 194 800 lb. (411.5 tons)

Equipment.

Turbine : One impulse type embodying a velocity-compounded impulse-control stage followed by four full-admission impulse stages.

Generators : Two, each double-armature; 1 760 amp. (continuous) per armature; 568 volts (continuous) per armature; 1 000 kW. (continuous) per armature; 1 000 r.p.m.

Traction motors : 620 H.P. (continuous) at shaft; 880 amp.; 568 volts; 720 r.p.m.

Auxiliary generators : Two, 9-kW.; 75 volts; 120 amp.

Gearing : Main unit, pinion, 45 teeth, 6 dia. pitch; 9 deg. helical angle.

Main unit, gear, 272 teeth, 6 dia. pitch; 9 deg. helical angle.

Traction motors, pinion, 24 teeth, 2 dia.; pitch; 6-in. face spur.

Traction motors, gear, 55 teeth.

Blowers : Steam-turbine-driven propeller-type fans; generator blower; 24 000 cu. ft. per min.; No. 1 traction motor, 9 000 cu. ft. per min.; No. 2 traction motor, 15 000 cu. ft. per min.

Control : Manual, by change of governor setting and change of generator fields.

[621 .132 .3 (.42) & 621 .132 .5 (.42)]

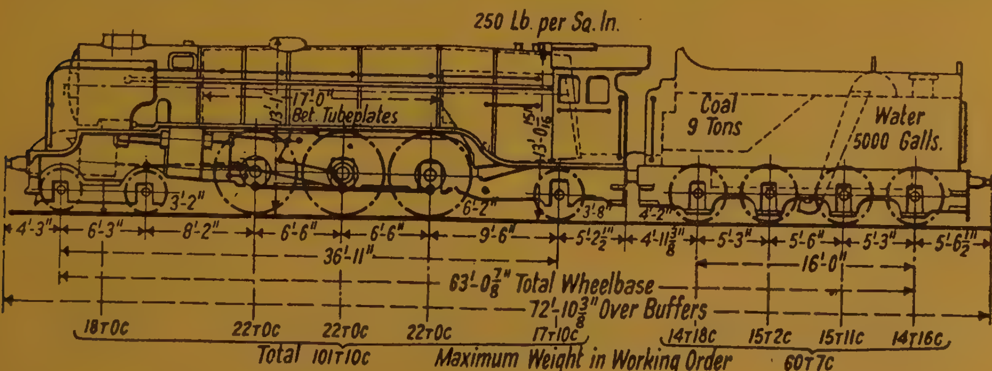
Final L.N.E.R. Pacific locomotive. Peppercorn 4-6-2 design.

Comparison with Thompson mixed traffic units.

(Modern Transport, January 3, 1948.)

The first of a new series of Pacific (4-6-2) express passenger and freight locomotives was completed at Doncaster works during December by the London and North Eastern Railway and, resplendent in apple green livery, is now in service on the main lines of the Eastern and North Eastern Regions of the British Railways. The new engine is numbered 525 and just before Christmas was named A. H. PEPPERCORN after her designer, the last chief mechanical engineer of the L.N.E.R. The ceremony took place at Marylebone Station, the naming being performed by Sir RONALD MATTHEWS, chairman of the L.N.E.R., who was accompanied by a number of directors and officers.

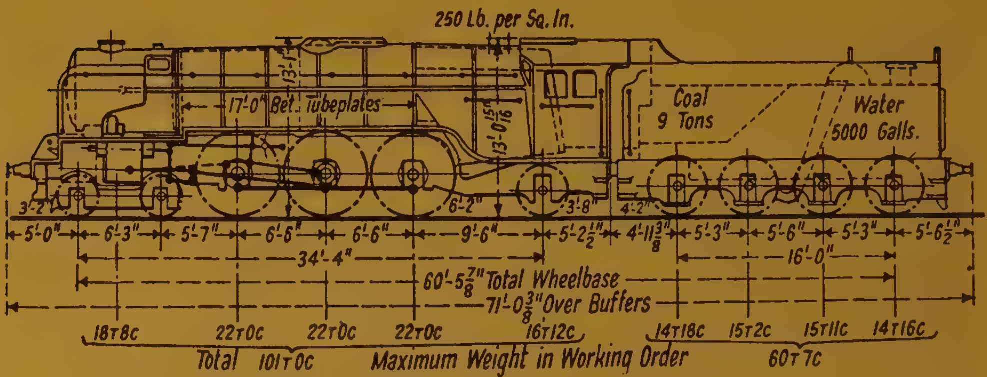
No. 525 is the 1 434th and the last locomotive to be built by the L.N.E.R. since the formation of the company twenty-five years ago; it is also the 2 016th engine to be constructed at Doncaster works. The new engine has been classified A2 and differs considerably in detail and appearance from those of the previous order built during the regime of Mr. Edward THOMPSON, now designated A2/3.



The L.N.E.R. Pacific of class A2/3 designed by Edward Thompson.

New cylinder position.

The three cylinders of 19-in. diameter by 26-in. stroke have been brought closer together by moving forward the outside cylinders to the more orthodox position between the bogie wheels, thus shortening the exhaust ports and eliminating the external exhaust ducts. At the same time the bogie has been brought back nearer to the coupled wheels, and the total wheelbase shortened by 2 ft. 7 in. As before, the drive is divided, the middle cylinder acting on the leading coupled axle and the outside cylinders on the middle axle. The inside connecting rod and Walschaerts motion is identical with that used on the previous locomo-



The new Peppercorn class A2 Pacific locomotive.

L.N.E.R. Peppercorn class A2 dimensions and ratios.

Boiler :

Maximum diameter of barrel, 6 ft. 5 in.
Overall length of firebox, 11 ft. 4 1/8 in.
Overall length of firebox at bottom, 7 ft. 11¼ in.
Overall width of firebox at bottom, 7 ft. 9 in.
Thickness of barrel plates, 5/8 in. and 11/16 in. (On A2/3 class, 7/8 in. and 13/16 in.)
Thickness of outside wrapper, 9/16 in.
Thickness of copper firebox plates :
Wrapper and backplate, 9/16 in.
Tubeplate, 9/16 in. and 1¼ in.

Tubes :

Small :
Number, 121.
Diameter outside, 2¼ in.

Superheater flue :
Number, 43.
Diameter outside, 5¼ in.

Superheater elements :
Number, 43.
Diameter inside, 1.244 in.

Grate :

Area	50	sq. ft.

Heating surface :

Firebox	245.3	sq. ft.
Tubes	1 211.57	sq. ft.
Flues	1 004.5	sq. ft.
Total evaporative	2 461.37	sq. ft.
Superheater	679.67	sq. ft.
Total	3 141.04	sq. ft.

Two Ross pop safety valves, 3½ in. diameter.

Axles :

Journals :	dia.		length.
Bogie	6½ in.	×	9 in.
Coupled wheels	9½ in.	×	11 in.
Trailing	6 in.	×	11 in.
Crank pins :			
Outside	6¾ in.	×	6 in.
Inside	9¼ in.	×	6 in.
Coupling pins :			
Leading	4¾ in.	×	3½ in.
Driving	7½ in.	×	4½ in.
Trailing	4¾ in.	×	5 in.

Cylinders :

Number, 3.
Diameter and stroke, 19 in. by 26 in.

Motion :

Type :
Outside, Walschaerts.
Inside, Walschaerts.
Type of valve, piston.
Diameter of valve, 10 in.
Maximum valve travel, 6¾ in.
Steam lap inside cylinder, 1 5/8 in.
Steam lap outside cylinder, 1 5/8 in.
Cut-off in full gear, 75 per cent.

Tractive effort at 85 per cent boiler pressure, 40 430 lb.
Total adhesive weight, 147 840 lb.
Adhesive weight ÷ tractive effort, 3.67.
Steam brake and vacuum ejector.

tives, while the outside gear has been lengthened and closely resembles that used on the now numerous B1 class of 4-6-0.

The boiler is unaltered in general dimensions and carries a pressure of 250 lb. per sq. in. The dome, however, has been replaced by a steam collector of the familiar L.N.E.R. pattern and the use of 3 per cent nickel alloy steel has enabled thinner barrel plates to be used.

The first of the new L.N.E.R. A2 mixed traffic class bears the name of the designer « A. H. Peppercorn ».

Improved look-out.

The provision of a wider cab has enabled the vacuum ejector to be lowered and together with a vee front considerably improves the look-out. The cab mountings and controls follow the usual L.N.E.R. practice for Pacific engines but include electric lighting, the current for this and the head-lamps being supplied by a Stone turbo-generator situated on the front right-hand side of the footplate.

To reduce disposal time at the sheds, a hopper ashpan, rocking grate and self-cleaning smokebox have been provided and these, together with the accessibility of the motion and valves, should assist the shed staffs in their routine examination. The principal characteristics of the locomotive, together with those of the previous engines, are shown on the two diagrams.

[385 .072 (.42)]

A railway scientific research organisation.(*)

Work of the laboratory established at Derby by the L.M.S.R.

(The Railway Gazette, February 20, 1948.)

A few years after the grouping of railways in Great Britain in 1923, a small committee was set up by the late Lord Stamp on the L.M.S.R. to report on the intensification of scientific research for that railway. In due course, a separate Research Department and a permanent advisory committee were set up, with Sir Harold HARTLEY as Vice-President

Inspecting a firebox with mobile X-ray apparatus.

and Director of Research. These steps were taken in 1930, and in 1932 the department was named the Scientific Research Department; Mr. T. M. HERBERT was appointed Research Manager. A separate directors' committee was appointed in 1939 to supervise the work of the Department, and ensure for it the interest and support of the Board of the L.M.S.R. Company.

Contact with the latest developments in scientific research was maintained through the company's Advisory Committee on Scientific Research, on which served half-a-dozen eminent scientists, who not only attended formal meetings under the chairmanship of the Vice-President, but also visited the company's laboratories for informal talks and gave guidance on promising lines of investigation.

By the end of 1947 the Scientific Research Department of the L.M.S.R. had a total staff approaching 200, and comprised six main sections, concerned respectively with engineering, metallurgy, paint technology, physics, textiles and chemistry. The Chemical Section maintains laboratories at certain centres to deal with divisional and local work, but the other five sections are housed in one building at Derby, which was opened formally in 1935 by Lord RUTHERFORD OF NELSON.

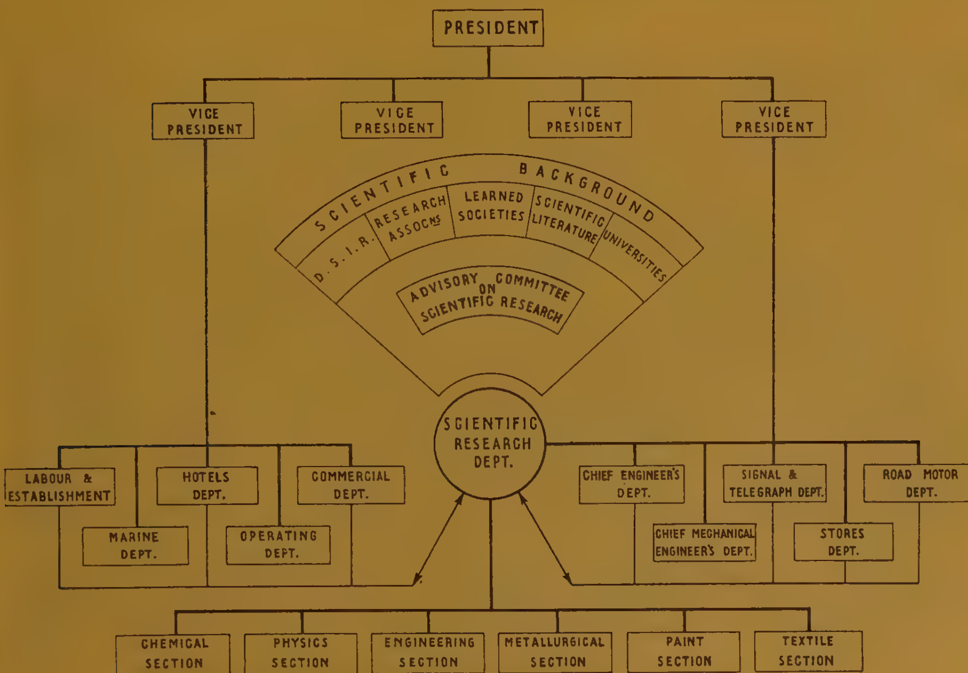
An important branch of study in the Engineering Section is resistance to wear. For this purpose a machine is used in which two rings of the material under test are forced together and rotated in opposite directions. The equipment includes provision for keeping the sample rings cool and free from abraded particles. This apparatus has been used for general investigations of wearing properties, and for assessing the relative merits of alternative materials for rails, wheel tyres and brake blocks.

An example of the special apparatus evolved at Derby is a machine for test-

(*) Based on information in the L.M.S.R. publication « The Scientific Research Department of the L.M.S. », published in 1947.

ing railway carriage axles, the weakest part of which, due to the force-fitting of the wheels, is known to be at the inner end of each wheel boss. As a result of tests with half-size models of axles, which were rotated several million times under load in the apparatus, an improved axle was designed which was adequately strong at all points.

a wind tunnel, in which tests are carried out on small components such as ventilators, filters, and signal lamps, or on scale models of trains, buildings, or station awning roofs, which are subject to currents of air at speeds up to 60 m.p.h. Other air flow research has led to improvements in automatic train control equipment, the cooling of diesel locomo-



Organisation of scientific research activities on the former L.M.S.R.

The section is equipped with magnetic supersonic, and electronic apparatus for measuring and recording pressures, stresses, and vibrations. Extensive use is made of resistance wire strain gauges; and for studying the distribution of strain in parts of complicated shape, photo-elastic models made of transparent bakelite are examined under polarised light.

An important feature of the section is

tives, and the maintenance of the vacuum brake system.

The Metallurgical Section of the laboratory undertakes work concerned with the selection, treatment, specification, inspection, and behaviour of metals and alloys. Recent studies have included the wear and corrosion of various types of rail, and the cause and distribution of rail failures. Much information of practical value has been acquired with re-

ference to welding, and the section gives demonstrations from time to time to welding supervisors and operators, using X-ray photography to give visual evidence of the soundness or otherwise of the work carried out.

The equipment of the Metallurgical Laboratory includes a 35-kVA. high-frequency spark gap induction melting furnace, together with a 2.5 kVA. resistance melting unit. Heat treatment is conducted in a small 14-kVA. G.E.C. furnace with automatic and recording temperature control, whilst a 9-kVA. G.E.C. resistor furnace, with automatic control up to 1 350° C., is available for high-temperature work.

Conductivity and magnetic types of detector are available for work on cracks. A specially developed contorgraph is used for studying the wear of rails, which draws a magnified profile of the worn surfaces of the metal when clamped to a rail in the track.

Important contributions to paint technology have been made by the Paint Section of the laboratory. Among the practical achievements has been the development of a painting process for coaches which permits an appreciable reduction in the number of coats required, while at the same time giving an improved appearance and longer life. The effects on paint of the varied atmospheric conditions met with in railway locations are studied by an accelerated weathering machine, enabling the useful life of a paint to be measured in a few weeks instead of in years.

Further improvement in the durability of exterior paintwork on carriages depends to a large extent on ensuring the adhesion of the stopping which is applied over the heads of countersunk screws used for securing the metal panels to the wood body frame. For this purpose a vibratory stopping tester has been designed to simulate the effects of vibration of a vehicle running at speed, the specimens being gripped in the jaws of the machine, which sets up vibration by a reciprocating motion.

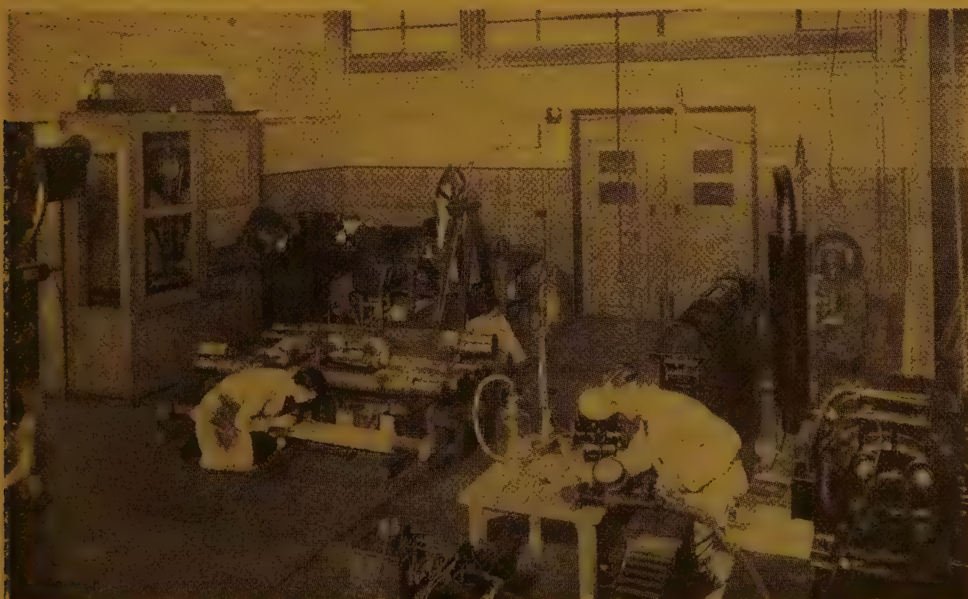
Hundreds of test paints are prepared each year in the laboratory in order to assist paint manufacturer by formulating the requirements for paints to fill the special needs peculiar to railway service.

The Physics Section is concerned with

Recording transverse movements of track under traffic.

problems in heat, light, and sound which arise in great diversity in railway work. Many of the activities of the section are carried on outside the laboratory, among them being those concerned with the transport of foodstuffs under refrigerated and controlled temperature conditions. The section's photometric laboratory carries out colour measurements to check the colours of signal glasses and engine firing methods at particular depots. The heavy computition in this work, and in mathematical calculations for other sections, is done on a calculating machine.

Materials ranging from fine sewing silks to heavy tarpaulins are subjected to inspection and testing in the Textile Section of the laboratory. This section deals primarily with acceptance tests of



An engineering test laboratory at Derby.

lenses used on all the British main-line railways. Extensive measurements are made of the illumination provided by lamps and lighting fittings, and during the war the section devised its own type of photometer for measuring the very low intensities of illumination permitted in certain outdoor lighting installations by A.R.P. regulations.

The section studies coal consumption figures from the motive power depots in order to assess the value of education in materials purchased, but has undertaken also certain research and development work, such as the production of an improved design of lubricating pad for rail vehicles. Since the properties of textile materials vary greatly according to the relative humidity of the atmosphere, this section is provided with a room where a temperature of 70° F. and a relative humidity of 65 per cent. are maintained. In this room are housed machines for measuring breaking loads and extensions

of yarns, twines and cloths, and also a Mullen tester for measuring the bursting strengths of materials. The fastness of dyed materials, rèsistance of fabrics to wear, and waterproof qualities are the subjects of other investigations in the department.

tion of rates and conditions of transport for much of the traffic passing over the system, and claims for goods alleged to be damaged in transit are investigated. The Chemical Section is at the service of the other sections of the scientific Research Department when chemical analyses are required. Certain works processes, such as those at steel works, are controlled from the chemical point of view, as well as those involved in the manufacture of coal-gas and train-lighting accumulators.

The general laboratory of the Chemical Section at Derby.

As mentioned at the beginning of this article, there are in all five chemical laboratories, located respectively at Derby, Crewe, Horwich, Glasgow, and Stonebridge Park (London). All are under the control of the Chief Chemist, whose office is situated in Manchester. Advice is given to the commercial and operating departments, as well as those engaged in technical matters. For example, assistance is provided in the classifica-

During the period of grouping the L.M.S.R. controlled more drinking water supplies than any other single interest in Britain, and it was the chemists' responsibility to safeguard their purity by sur-

vey of wells and gathering grounds, and by chemical and bacteriological examination, as well as to advise on any necessary treatments.

An activity of recent development is the work of the Infestation Section, which controls insect infestation in railway premises, including stables, warehouses, hotels, refreshment rooms, and vehicles. The equipment of the laboratory dealing with this work includes much up-to-date apparatus designed for rapid and accurate determination by physico-chemical methods, as well as facilities for micro analytical work.

The benefits of the research carried out at Derby have been made available on a wide scale by the active encouragement given to members of the staff to publish papers based on their work. An annual award, known as the Herbert Jackson Prize, is made to the best-written account of work carried out by members of the scientific or technical staff in the course of their normal employment, and consists of a medal and a monetary award. This award was founded by the Board of the L.M.S.R. in 1937 in memory of the late Sir Herbert JACKSON, F.R.S., the eminent scientist who was one of the original members of the L.M.S.R. Advisory Committee for Scientific Research.

[625. 172]

Prevention and destruction of weeds on the permanent way.

(The Railway Gazette, April 16, 1947.)

In the course of a year, permanent way maintenance gangs spend a considerable amount of time in clearing the tracks of weeds that have obtained a foothold in the ballast. The present acute shortage of labour has increased the difficulties of keeping the road in good condition, and practical measures for arresting the growth of weeds are worthy of consideration. A number of suggestions, based on many years of experience as a length ganger were advanced by Mr. F. Wensley, in his paper on « Prevention and Destruction of Weeds on the Permanent Way », at the meeting of the South Wales Section of the Permanent Way Institution, held at Neath on March 20.

It may be assumed that the soil used for the formation of railway embankments contained the seeds and roots of many perennial weeds, which soon showed themselves in the ballast and cesses and became an increasing source of trouble to the maintenance gangs. So deeply-rooted are these plants that ordinary hand weeding may fail to eradicate them. Indeed, the light use of a weeding tool serves only to prune the roots, and an even more luxuriant crop results. If deep digging is undertaken, it is most important to remove the roots of perennials completely, as any fragments which remain are encouraged to grow by the disturbance of the ballast, and by having fresh soil placed round them.

The expedient of renewing the ballast has been tried on certain lengths, where perennial weeds have become particularly troublesome. This has not always had the desired effect, as the new material appears to have acted as a fertiliser, and, after a comparatively short interval, the laborious work of hand weeding has had to be resumed.

Annual weeds, although not so deeply-rooted as many perennials, call for special attention, as they grow quickly, and seed profusely. Certain hardy types may even continue to flourish throughout the winter. Three of the commonest varieties, ragwort, sow-thistle, and groundsel, have light airborne seeds, which can be scattered over a wide area by the wind raised by passing trains. Seeds of this type tend to settle in cuttings, where there are pockets of relatively still air. Plants bearing an « explosive » type of seed pod scatter their seeds over a restricted area, but they multiply quickly, and a heavy crop of weeds results.

It is of the utmost importance to prevent annual weeds from seeding, as a single plant may produce as many as 40 000 airborne seeds. Moreover, many weeds mature rapidly, and flower and bear seeds within three weeks of their first appearance. In dry weather, light digging with a weeding tool is sufficient to cause most lightly-rooted annual weeds to wither, but if the season is wet, they should be removed from the ballast, or they may take root again and recover. Airborne seeds also can reach the track from neglected land adjoining the railway, over which the maintenance gangs have no control.

The grasses growing on embankments and the sides of cuttings can give serious trouble, if they are allowed to seed on to the ballast. This can be prevented by cutting the grass early in the summer, before the seeds have formed. A second

cutting in August or September, is advisable, to prevent late seeding. The wisdom of allowing the grass to mature, to provide a crop of hay, may be questioned, as it is impossible to prevent some of the seeds from reaching the ballast. If the grass crop is cut and burnt on the banks, the bare patches caused by the fires encourage the growth of weeds. Not only do airborne seeds have unimpeded access to the ground, but the fertilising action of the ashes stimulates their growth.

Decaying vegetable matter in the ballast encourages the growth of weeds, and every effort should be made, in the autumn months, to clear fallen leaves from the track. Also, the seeds of many trees growing beside the railway germinate readily in the ballast and develop quickly into small bushes. These seedings can be uprooted easily, but, like annual weeds, they should be removed at once in wet weather, or they will revive.

The disposal of old and dirty ballast has an important bearing on the problem of weed prevention. This material contains thousands of seeds, which will grow readily if the ballast is tipped down a railway embankment, or left lying in heaps by the lineside. It may not be realised generally that many airborne seeds are carried by the wind into tunnels, where they become coated with soot, and lie dormant until the ballast is removed. The practice of removing spent ballast to a dump has much to commend it.

Of equal importance is the disposal of weeds that have been removed from the ballast. Experience has shown that it is preferable to collect them into large rather than small heaps, so that the area over which seeds are scattered may be reduced to a minimum, and there is less chance of weeds being overlooked when they are cleared away. The loose soil removed with the weeds should not be left in heaps, which will become nurseries for more weeds, but should be scattered.

The introduction of weed-killing trains, fitted with chemical sprayers, has alleviated considerably the task of the maintenance gangs, but it is not always easy to find paths for these trains on lines that carry a heavy traffic. Moreover, if the weed-killing unit has to cover an extensive district, it may not be possible for it to operate on a particular section of line before the weeds have seeded. The provision of additional units would go far towards solving this latter problem, particularly on lines where the traffic is relatively light.

Additional assistance could be afforded by the use of chemical weed-killer by the maintenance gangs. It has been suggested that particularly obstinate patches of perennial weeds could receive intensive treatment in this way, when the remainder of the length does not require spraying. In this connection it may be noted htat weed-killing powder, packed in tins with perforated lids, has been used successfully in places which cannot be reached by the sprayers. It has been suggested also that the growth of perennial weeds could be checked by spraying or dusting the under ballast when relaying is undertaken. On the other hand, a proposal for mixing powdered weed-killer with new ballast, before it is delivered to the site, appears to be impracticable, as the new material would have to be kept dry until it was laid.

NEW BOOKS AND PUBLICATIONS.

[656 (.54)]

SLAUGHTER (E. W.) C. B. E., M. I. Mech. E., M. Inst. T., General Manager Nizam's Railway 1935-1941; Managing Director Nizam's Railway Board 1941-1946. — **The Co-ordination of Road, Rail and Air Services in Hyderabad State, India.** Experiences in the field of British transport vehicles and control of State-owned services under one Administration. — A pamphlet (7 × 9 ½ inches) of 32 pages, with illustrations and a map and graphs.

The State of Hyderabad, the largest in India, covers 35 000 square miles, which is about the same size as Great Britain, with a population of about 18 million, mostly Hindu. There is a fair amount of industry. The country produces sugar, paper, cement, textiles, starch, metals, alcohol, leather, matches and cigarettes, all industries in which the State has an interest. There is also coal, some million tons a year being produced, a figure which could be increased.

The railway extends to some 1 360 miles of line, divided about equally between wide and metric gauge. The geographical situation of the country embraces the routes linking up Northern and Southern India, as well as communications between the east and west coasts.

Apart from a certain development of road traffic after 1918, owing to the purchase of second-hand light vehicles, it was not until 1932 that any harmful effect on the railway revenue was experienced.

The question of road competition and the co-ordination of transport then arose, a question which at that time was also of great concern to the managements of European railways. It will be remembered that the subject was discussed at the Cairo Congress (1933) after the Madrid Congress (1930). The summaries then adopted can profitably be read again as they have lost nothing of their topical interest.

The author deals with the co-ordination measures taken in the State of Hyderabad. In his introductory note, he warns his readers that in general circumstances are very different to those in England, and we might add in most European countries. The results obtained cannot therefore be quoted as an example to justify a similar policy elsewhere. Nevertheless, it may be remembered that these measures proved of value, and others may be inspired by them.

It is not possible to give a detailed analysis here, but it can be stated that the solution adopted was to give a single authority, in actual fact the railway, the monopoly of rail and road transport. The mission with which it was entrusted in the case of the road in particular is summed up in five points, and the methods by which the desired end was attained are clearly given. The effectiveness of this unified operation is clearly shown by the statistics given in the form of graphs showing the progression of the traffic and the gross and net receipts. A great improvement in the value of the services offered to the public has also to be credited to the new organisation.

To sum up, here is a document of the greatest value to include in the dossier of the co-ordination of transport.

E. M.

[385. (09 .3 (.494)]

MATHYS (E.). Librarian to the Swiss Federal Railways. — **Hundert Jahre Schweizerbahnen. Historisch und Technisch dargestellt. - 1841-1941.** *(The Swiss Railways in the course of a century. A technical and historical review. - 1841-1941).* Second edition. — One volume (6 × 8 ¼ inches) of 268 pages, illustrated, with additional maps. — 1943, Berne. Published by the Author.

The author has often been asked for various information concerning the people connected with the construction, operation and history of the railways. In order to facilitate research into this matter, he had the happy inspiration of using his knowledge to collect together methodically in this book a great number of facts of statistical or historical interest.

The first edition was entitled « Important events and data concerning the Swiss railways, 1841-1940 ». It was so successful that the author was led to make certain improvements and as the additions made chiefly consisted of technical notes which changed the character of the work, a new title was adopted which seemed more appropriate.

The book contains an analytical table concerning the building of the lines; in each case the date it was opened to traffic is given, together with the length in operation. The lines are first of all grouped in chronological order, and then alphabetically. Similar tables give the reader full details on the work of electrification, double track lines, the building or reconstruction of stations. These statistics cover not only the standard gauge but also the narrow gauge lines, as well as the tramways, rack railways, overhead railways and trolleybus lines. On the way, the author devotes several very interesting pages to the most characteristic technical inventions, for example steam locomotives, electric locomotives and special types of locomotives.

In a country like Switzerland, the construction of tunnels and bridges cannot fail to be of interest. The tables dealing with these structures, some of which created new records, give some idea of the titanic work which the engineers had to achieve to overcome natural obstacles.

Statistics of accidents and a brief review of the safety measures in use show the care taken by the Swiss Federal Railways to provide against accidents and the use made in this connection of the latest inventions of modern science.

A brief history of the nationalisation of the railways, which was decided upon by the law of the 15th October 1897, approved by the referendum on the 20th February 1898, is preceded by a complete list of the concessions granted with their dates. Later on there is a list of the lines that were purchased.

The book is illustrated by many drawings. There are pictures of remarkable structures and scenes, of characteristic types of stock, or portraits of the men whose names are linked up with far-reaching reforms, important events or technical improvements which marked a stage in the history of the railway.

The author deserves many thanks for producing a document of great value which is also a tribute to those whose efforts have culminated in a remarkable railway system, often in spite of many difficulties.

E. M.

[385. (09 .3 (.42)]

DOTT (George). — **Early Scottish Colliery Wagonways.** — A pamphlet (6 × 9 inches) of 32 pages with illustrations and maps. — 1947, London, St. Margaret's Technical Press Ltd., 33, Tothill Street, Westminster, S. W. 1. (Price : 2/6d.)

We know that the first tracks laid on the ground to facilitate the movement of vehicles were used in connection with the transport of coal. At least, this was the case in Scotland where all railway tracks laid before 1930 were either owned by a colliery or used in connection with a public service established solely or primarily for carrying coal.

The making of these tracks goes back to a far distant time. The oldest mentioned by the author was laid in 1722. It is very interesting to read this history, short though it is. The description of the equipment provided with very limited resources, together with brief details of the vehicles and traction methods used, enable interesting comparisons to be made with modern practice. Looking back to these far distant times, one cannot but admire the pioneers of railway lines.

This passionate interest in events whose origins are lost in the obscurity of time is understandable. The author is a miner as well as a railwayman, the two activities being closely connected. He wished to add his contribution to the great work of the late C.F. DENDY MARSHALL on the beginnings of the railway. To this end he consulted the best sources, with which he was already familiar owing to his research work in connection with the Scottish coal mines. At least 24 lines are known to have been worked, and in each case the documents consulted have enabled the date of the original construction to be determined, as well as the types of waggons, rails and sleepers used, together with the dates and the description of the modifications made to the track and vehicles, the date when the line was abandoned or incorporated into a more up-to-date system, and the introduction of steam traction.

Each page of this little book is packed with valuable information. However well-informed the reader may be, he cannot fail to be struck by the poverty of the resources originally available. When rails are mentioned, these are not yet iron bars but simply wooden beams, square in section, sometimes double, i.e. made of beech laid on pine. Later on they were completed by a flat piece of iron. Cast rails with a curved section came later. The waggons originally had wooden wheels; on the first line described they could carry three tons and were pulled by one or two horses.

Maps are given showing the layout of the lines, together with drawings of the primitive rolling stock and equipment, certain traces of which the author came across during his investigations.

The author must be congratulated on the use he has made of the obscure documents he had to consult. Behind his care to obtain accurate information can be divined a profound attachment to his subject and his admiration for the men of the period.

E. M.

[656 .281]

LAFFITE MARTINEZ (Carlos). — Engineer of industry, Under-Director of the Metropolitan Company of Madrid. — **Teoria del Descarrilamiento** *(Theory of derailment).* — A brochure (6 ½ × 9 inches) of 44 pages, illustrated. — 1943, Madrid, Asociacion Nacional de Ingenieros Industriales.

The object of this note is to elaborate the theory of derailment.

The author recalls first the empirical theory which, in considering the conditions required to cause the wheel to slip over the rail, gives a formula expressing as a function of the angle of the tyre and of the coefficient of friction, the relation of the thrust to the load. If this extreme value is divided by the actual value the coefficient of safety is obtained. The formula varies according to whether the angle of thrust is positive or negative, but is only of interest in the former case.

The theory consequently developed rests on a further analysis which seeks to locate accurately the position and movement of the point of contact. This leads to a fresh formula, rather more complicated, which takes into account the angle of thrust and the radius of the wheel. A graph is compiled to shew the relation between the thrust and the load when $r = 0.50$ m. (1′7$^{11}/_{16}$″) and offers a comparison with the single value of the classical formula and also with the Wagner formula used in Germany. Another graph is drawn to shew the influence of the size of the wheel radius. As regards the angle of the tread, the article advises that it should not be reduced below a certain value. According to the classical formula, the degree of safety would increase with the angle.

In examining sliding and skidding, the author expresses the opinion that it is preferable not to brake guiding wheels.

In the chapters which follow there is a study of the question of derailment from the dynamic point of view, an attempt to determine horizontal thrust and some remarks on hunting and running through curves.

As a result of his investigation, the author offers several recommendations which seem to him to tend to increase the safety factor. The principal ones are given below :

It is advantageous to lubricate the wheel flanges and, in curves, the rails also. The angle of the flanges may, in certain circumstances, be fairly high. The guiding wheels should be of small diameter. The use of a suitable device will give these wheels side control and damp displacement. Braking is undesirable, but its influence is less on small wheels. A low angle of thrust is good, but a negative angle is preferable, particularly with high-speed stock and this can be obtained with radial axles.

As regards the track, long rails are recommended. Adequate resistance to lateral displacement is needed. Curvature, as well as superelevation, should be regular. Transition curves should be at least as long, in metres, as the speed has km. per hour and the superelevation cant should be not more than one-sixth of the speed.

In curves of less than 300 m. (984′3″) radius, judicious use may be made of check rails.

E. M.

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